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USSR REPORT  
SPACE BIOLOGY AND AEROSPACE MEDICINE  
Vol. 17, No. 5, September-October 1983

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### STUDY OF CARDIOVASCULAR SYSTEM DURING LONG-TERM SPACEFLIGHTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 19 Aug 82) pp 4-6

[Article by A. D. Yegorov and O. G. Itsekhovskiy]

[English abstract from source] During the Salyut-6 spaceflights cardiac bioelectrical and mechanical activity, blood content and tone of cerebral and limb vessels, systemic arterial and venous pressure were measured in 10 primary crewmembers. The measurements were taken at rest and during LBNP and ergometry tests. The study has shown that the circulation changes are adaptive reactions of the body to a new environment, particularly weightlessness. Cardiovascular responses to the provocative tests were changed and more marked, probably, due to blood redistribution.

[Text] Medical studies during spaceflights lasting up to 6 months failed to demonstrate any pathological changes in function of the cardiovascular system; however, they revealed that changes in parameters reflected the process of adaptation to new environmental conditions, particularly weightlessness. An effort was made here to sum up the preliminary results of these studies and systematize the findings.

During the flight, equipment was used to record the EKG in the 12 clinical leads, apical kinetocardiogram, tachooscillogram of the arm, sphygmogram of the femoral artery [1], phlebogram of the jugular veins [2], occlusion mechanoplethysmogram of the crural region, rheograms of the trunk, head and extremities.

Studies with the subjects at rest revealed that, for the first month of the flight, heart rate had a tendency toward decline (in 4 cosmonauts) and later to a mild increase in most cases. The changes in phase parameters of the cardiac cycle were usually manifested in flight by shortening of phases of isometric contraction and relaxation, extension of period of ejection and rapid filling. Rheography demonstrated a tendency toward higher minute volume (MV) throughout the flight (by 11-17%), as compared to preflight values, and greater stroke volume (by 13-32%) for the first 10 days. The parameters of blood pressure (BP) did not change, or else presented a tendency

toward decline (with the exception, of course, of systolic pressure). Specific peripheral resistance and its relation to nominal values decreased by 11-64%, while the rate of propagation of the pulse wave in the aorta, on the contrary, increased by 11-24%, without distinct dependence on duration of the flight.

Typical distinctions were demonstrated in the dynamics of systemic venous pressure; it rose in the jugular vein and dropped in the crural region, which was indicative of leveling off of venous pressure gradient.

Elasticity of crural veins increased while contractility, on the contrary, decreased. In this region, there was also progressive decline of arterial influx. At the same time, rather high vascular tone was retained in the brachial region, and arterial influx increased.

Rheoencephalography revealed an increase (in 6 out of 10 cosmonauts) in pulsed filling of cerebral vessels, with a maximum on the 50th-85th day, after which there was a tendency toward recovery or even decline. The parameters of tonus of precapillary and postcapillary vessels diminished, and in some cases signs of venous stasis and marked dilatation of small vessels were demonstrated. Pulsed filling of crural vessels, as well as parameters of tone of large arteries in this region, consistently diminished, whereas in the forearm pulsed filling increased and vascular tonus was somewhat diminished.

Evidently, the above changes are based on adaptive reactions of the circulatory system to the specific effect of weightlessness and relative hypodynamia. Shifting of blood in a cranial direction first elicits an increase in venous return and volume load on the heart, as well as increase in pulsed filling of cerebral vessels. The absence of load on the vast muscular mass that performs antigravity and tonic postural function, as well as the constant shortage of muscular activity in limited space probably diminish the activity of the peripheral heart [3, 4] and increase the role of systolic function of the heart and its pumping function in hemodynamics. At the early stages of the flight, there is the most vivid manifestation of compensatory reactions: inhibition of vasomotor center, increased tonus of the vagus and triggering of unloading reflexes, removal of part of the fluid and reduction of central blood volume, stabilization of circulation on a new functional level as a result of triggering compensatory mechanisms from the carotid sinus. The redistribution of blood lowers the pressure gradient in the upper and lower parts of the body, while hypovolemia in the region of the legs causes increase in elasticity and capacity of the venous reservoir of the lower leg.

According to the inflight EKG data, the changes were not clinically significant; they did not affect hemodynamics or health status of the cosmonauts.

Functional tests with LBNP [lower body negative pressure] (with rarefaction of 22 mm Hg for 2 min and 35 mm Hg for 3 min) in weightlessness were generally associated with somewhat more marked responses than on earth. This was manifested by a greater (by 16-27%) increase in heart rate of half the subjects and decrease in circulatory blood volumes: by an average of 7-29% for stroke volume and 11-43% for minute volume. There was a change in relationship between duration of phases of the cardiac cycle, as compared

to the preflight period; there was less marked increase in absolute duration of phases of isometric contraction and relaxation under the influence of LBNP than before the flight, while peripheral filling and, in particular, the phase of rapid filling decreased to a greater extent. The intrasystolic index was above preflight values in 4 out of 6 cosmonauts and lower in 2.

The parameters of arterial pressure with LBNP were also lower in a number of cases than preflight values, particularly minimal BP. In most cosmonauts, the levels of specific peripheral resistance and rate of propagation of pulse wave over the aorta were considerably higher in the flight tests (both before and during LBNP) than preflight values, and there was also an increase in relative increment of these parameters.

The typical distinction of changes in cerebral circulation, according to in-flight rheoencephalography with use of LBNP, was that there was more constant and more marked increase in parameters of tonus of large, as well as precapillary and postcapillary cerebral vessels. However, since there were signs of dilatation in the initial state during the flight, there was a tendency toward normalization of vascular tonus under the influence of LBNP. The studies failed to demonstrate a distinct correlation between extent of decline of orthostatic stability (in tests during the flight and postflight periods) and flight duration.

Such factors as relative dehydration of the body, decline of vascular tonus and deconditioning of mechanisms of venous return [4-7] could be relevant to the decreased orthostatic stability during and after spaceflights. As a result, inflight LBNP elicits greater displacement, as compared to ground-based conditions, of blood from the chest, where the initial volume is probably increased, to vessels in the parts of the body located in the decompression zone. This is confirmed by the greater increase in volume of the lower extremities with relatively low levels of LBNP [8] in flight, which could be related to formation in them of zones of free stretching of veins [9] as a result of low transmural pressure. The drastic decrease in blood volume in the cardiopulmonary region could, in a reflex fashion, increase activity of the vasomotor center and intensify adrenergic influences [10]. There is compensatory increase in heart rate and vascular tonus.

Functional tests with graded exercise also revealed a number of differences, as compared to preflight data. The changes in parameters of hemodynamics and phase structure of the cardiac cycle consisted of the following: the heart rate was higher than on the ground during inflight exercise in only 3 cosmonauts--FLE-1 [flight engineer], FLE-2 and CDR-4 [commander], and in the latter it was due to the heavier exercise. During the period of early recovery, there was more marked reduction of absolute duration of phases of isometric contraction and relaxation, less marked shortening of absolute duration of ejection period, greater increase in VSP [intrasystolic index?], shorter phase of rapid filling, which did not change before the flight or else increased.

The changes in circulation volumes were generally characterized by an increase in formation of MV with regard to its role in chronotropic function

of the heart. Unlike the ground-based dynamics, the increment of SV under the influence of the inflight load decreased drastically or was absent. The parameters of arterial pressure and peripheral vascular resistance also increased to a lesser extent than before the flight, with rare exceptions. At the same time, absolute rate of propagation of the pulse wave over the aorta increased to a greater extent during the inflight tests.

The assumed mechanism of cardiovascular changes during exercise loads and the period of early recovery is largely determined by the initial state before the test: decrease in total blood volume and interstitial fluid, increased volume in the cardiopulmonary region, increased elasticity of crural veins and possible formation of zones of free stretchability of veins. Some increase (or none) is observed in stroke volume of the heart under the effect of exercise, as a result of deposition of blood in vessels of working muscles and insufficient increase in venous return. The pulmonary blood volume probably increases [11]. During the early recovery period, when tension on the walls of venous vessels is removed, there is intensive filling of the venous reservoir, as a result of which there is decrease in blood volume, and pressure in the cardiopulmonary region elicits reflex increase in tonus of the sympathetic nervous system, which had been previously activated by exercise. There was more marked manifestation of intensification of adrenergic influences on myocardial function, and this is what causes the change in phase structure of the cardiac cycle.

Thus, on the basis of the findings, it can be assumed that the functional changes in the circulatory system during the flight were attributable primarily to the body's adaptation to weightlessness and hypodynamia. The typical changes in parameters resulted from hypervolemia of the upper part of the body, triggering of unloading reflexes, hypovolemia of the lower part of the body, decrease in effective circulating blood volume and increase in capacity of the venous system of the lower extremities.

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SIMULATION OF CEREBROCRANIAL TRAUMA FOR EVALUATION AND DEVELOPMENT OF  
GEAR TO PROTECT PILOTS AGAINST IMPACTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17,  
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[Article by A. S. Barer, V. I. Kharchenko, Yu. G. Konakhevich, L. N. Sholpo,  
G. N. Dubal'skiy, V. Kh. Petlyuk and N. A. Uglanova]

[English abstract from source] This paper reviews the results of developing a model of craniocerebral trauma. The study led to the manufacture of a man's head model and to the development of a criterion of impact safety. The model and the criterion can be used for experimental assessment of pilot's protective helmets.

[Text] A summary is given here of the principal results of our previously published studies dealing with development of a model of cerebrocranial trauma in order to use it for assessment of impact-protective properties of pilot helmets. We shall also discuss some data that were not mentioned in previously published works. These studies were prompted by the inadequacy of existing methods of testing protective helmets, in which hard head casts are used, on the one hand [1, 2], and the existence of a general scheme for simulating cerebrocranial trauma, which was based on clinical studies [3-5, 18-22], and investigation of biomechanics of the human head and skull in the presence of impact, on the other hand [6-9].

Work on physical simulation of cerebrocranial trauma for assessment of shock-proof properties of helmets [10-16] was pursued in the following directions: experimental study of biomechanics of the human head submitted to impact (including cadavers and isolated skulls); mathematical modeling of a blow to the head; probabilistic forecasting of clinical manifestations of cerebrocranial trauma and choice of a criterion of the trauma hazard of a blow to the head; physical simulation of a blow to the head and refinement of methods of testing protective gear.

Experimental studies [11, 13] were conducted primarily on a stand, which consisted of a pendulum, with characteristics similar to mathematical, equipped with a system of automatic elevation to a specified angle, descent and stop after impact [Figure 1a). The rate of approach to the barrier was



set in the range of 0.3-7.5 m/s. The tested object (human skull, physical model of the head) was attached to the bottom end of the pendulum by means of a special device that did not have an appreciable effect on its frequency characteristics, and it was equipped with acceleration sensors in the counterblow zone and in the central zone of the base of the skull (model). For in vivo studies of dynamic characteristics of the scalp [13], the stationary base of the stand is replaced with a seat with headrests (Figure 1b), and the pendulum was equipped with pins, to which samples of impact surfaces, acceleration sensors and, if necessary, additional weights were attached (Figure 1c).

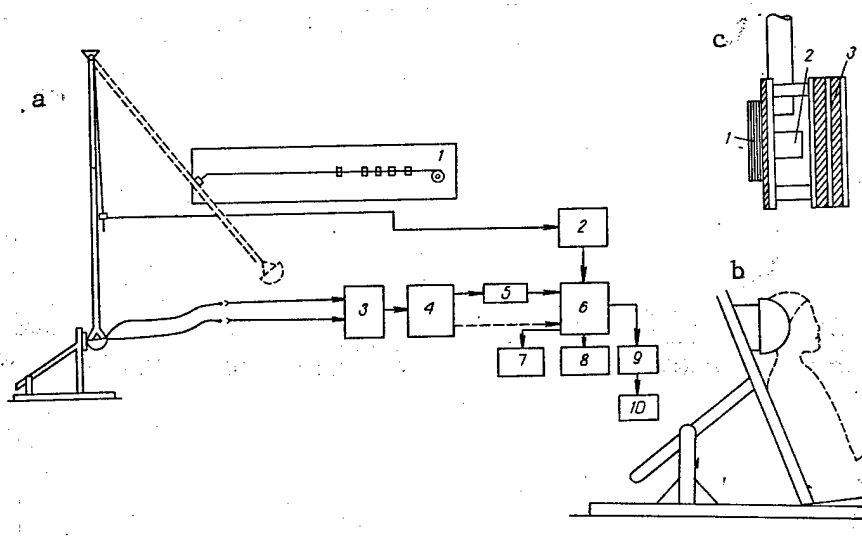


Figure 1. Experimental SUM-3 stand

a) general sketch:

- 1) automatic system for raising and stopping pendulum
- 2) circuit for automatic start of alphanumeric computer
- 3) amplifier
- 4) amplifier-transformer
- 5) tape recorder
- 6) ATAS 501-20 alphanumeric computer
- 7) teletype
- 8) graph plotter
- 9) punch
- 10) M-220 computer

b) seat and headrest for in vivo experiments

c) pin for in vivo experiments:

- 1) sample of material of impact surface
- 2) acceleration sensor
- 3) additional removable weights

Special software was developed for translation and analysis of the results, which made it possible to scale the signals, assess the main parameters of impact pulses ( $n$ --coefficient characterizing the shape of the leading edge,  $n^*$ --the same for the trailing edge,  $\beta$ --ratio of velocity of recoil to initial velocity of impact,  $b$ --coefficient characterizing local resilience for instances of impact with different surfaces), as well as to obtain digital integration to obtain the dynamic force characteristics, effect analytical approximation of the pulse with sine-cosine ratios, assess the quality of this approximation, perform spectral analysis and computation of transfer characteristics of the "sinciput-base" system of the skull and model of the head, etc.

About 350 experiments were performed to study the dynamics of the base of the isolated human skull with impact to the sinciput [11], using barriers differing in hardness (8 gradations). The blow was applied to the frontal, temporal and occipital regions at the rate of 0.3-4 m/s. It was established that there was complex oscillatory motion of the central zone of the base of the skull in relation to its sinciput.

The absolute acceleration extremum for the base of the skull is reached at the time of maximum acceleration on the sinciput oriented to the outside (out of the cranial cavity) with blows to the frontal region and to the inside with blows to the occiput and temples. Extreme shifting of this zone of the base in relation to the sinciput is obtained 4.5-9.9 ms after the impact, and it coincides in direction with the absolute extremum of acceleration.

Significant and close to linear correlations were demonstrated for the acceleration extremum at the base of the skull as a function of velocity of impact and parameter  $n$ , which determines the nature of the force characteristic in the impact zone. No statistically significant link was demonstrable between parameters of motion of the base of the skull and velocity of recoil.

The basic resonance was found at a frequency of  $800 \pm 150$  Hz and appreciably weaker resonance in the vicinity of 390 and 1200 Hz as a result of analysis of frequency characteristics of the "sinciput-base" system. An approximate estimate of extinction time constants directly from experimental curves yields a value on the order of 3-5 ms for all three frequencies.

A three-element viscoelastic model with concentrated parameters was chosen for mathematical modeling of the dynamics of the base of the skull [12]. It was realized on a Dnepr digital computer--MPT-9 automatic computer complex, revealing that even such utmost simplification provided satisfactory qualitative approximation of experimental data, in particular, there was rather good coincidence of distributions of acceleration extremums as a function of time in the model and in the experiment. This confirms the applicability of a linear model with concentrated parameters, at least for qualitative analysis of the phenomenon under study.

The absolute acceleration extremum of the central zone of the base of the skull in sincipital coordinates was taken as a gauge of burden on the base

of the skull and related cerebral structures (parameter S). To evaluate the critical values of parameter S, we used probability of occurrence of different degrees of impaired consciousness as a regression function of velocity of impact with a stationary barrier and localization of the blow (we did not take into consideration the hardness of the impact surface), which was obtained from analysis of records on cerebrocranial trauma [5]. The value of S was considered critical when it corresponded to impact conditions, under which the probability of severe impairment of consciousness exceeded 5%.

The results of the studies enabled us to propose a method of testing protective helmets, using the isolated human skull as a physical model of the head and parameter S as an estimate of trauma hazard of a blow to the head, at the first stage. About 100 experiments were conducted using this method to make a comparative evaluation of the shockproof properties of different types of aviation and athletic helmets. The experiments were conducted on the stand described above, where wood, metal and the pilot's headrest were used as impact surfaces.

The results of these tests made it possible to assess and compare helmets of different types and the different zones of each helmet and to make a preliminary determination of the range of their trauma-preventive use. Analysis of shock-absorbing characteristics according to the readings of the acceleration sensor in the counterimpact zone made it possible to demonstrate the effects of material and structural features of the helmets, as well as the inner linings of different elements, on absorption of impact energy and to offer some preliminary recommendations on the choice of the above parameters of helmets.

To upgrade the method described above, the skull was replaced with a physical model of the head made of composition materials [15], which is more adequate from the standpoint of deformation and more convenient to work with, and the prognosis was defined as to the state of a victim of cerebrocranial trauma with consideration of the biomechanics of blows to the head [16].

Use was made of data obtained from the above-mentioned experiments with isolated skulls [11], as well as the results of studies on impact burden on the human skull [23] and cadaver head [8, 9], in which oscillograms of impact pulses were furnished, to select the system of analytical description of local deformation of the head upon sustaining a blow [14]. A special series of studies (178) was also conducted of the dynamic characteristics of the human scalp in vivo in the range of impact energies known to be safe from the standpoint of trauma [13].

It was assumed that the chosen model of local deformations would conform to our conceptions of the physics of the phenomenon under study, and that it would provide good analytical approximation of impact pulses (for generalization and comparative analysis of our own data and those in the literature), that it would permit reconstruction of the impact pulse to the victim's head from the description of circumstances, under which trauma was sustained (in order to compare it to clinical data when elaborating a criterion

of tolerance of blows to the head), use the results of the studies to estimate parameters of local reaction of living integumental tissues of the head over the entire range, with which we are concerned.

To perform this task, we used the correlations in semiempirical impact theory [17], which takes the elastoplastic deformation as an exponential function of contact force as the local force characteristic and uses long-wave approximation to describe the motion of centers of mass of colliding deformable bodies. To assess the comparative relevance of different factors determining the nature of the blow, we used a set of programs for statistical analysis, which were specially developed for the 15VSM-5 microcomputer. The obtained results confirmed the assumption that there were invariable parameters of local dynamic force characteristics ( $n$ ,  $b$ ) with respect to energy and pulse of impact, and they demonstrated that these parameters depended significantly on localization of the blow and material of the collision surface. Thus, base data were obtained for a model of local deformation of the human head submitted to an impact load.

Solving the impact equations made it possible to obtain estimates of the main parameters of impact pulse (maximum contact force or acceleration, overall duration and duration of leading edge) as a function of adjusted velocity of impact, mass of colliding bodies, resilience of collision surface and localization of blow. The estimated values of these parameters conform well with the obtained data for virtually all instances of collision with the skull, human head and cadaver head.

Since, with the exception of a few special cases, the impact equations are not solved by squaring, while the obtained relationships between parameters are quite cumbersome, a special program was developed for calculating them on a 15VSM-5 microcomputer, and an approximate graphic evaluation was made using the nomogram illustrated in Figure 2.

Our data and those in the literature concerning dynamics of local and general deformation of the human head upon sustaining a blow enabled us to validate the specifications for a physical model of the head. Such a model was developed and manufactured with an epoxy polymer [15] in the form of a flattened ellipsoid of rotation with flat base situated at an angle of  $20^\circ$  in relation to the forehead-occiput axis filled with water (Figure 3). This model, which was named "Mangust" (mechanical analogue of the head for impact stands) conforms well to the cranium in such characteristics as dimensions, mass and flexibility.

The quality of simulating the human skull with the Mangust model was checked in special tests (about 400) of collisions of different zones of the sinciput with wood and metal barriers at velocities of 0.8-5.2 m/s [15]. Statistical analysis of the results revealed that there was good coincidence of parameters of local force characteristics of the sinciput of the model and human skull, as well as principal resonance frequencies of oscillations of the base of the model and skull.

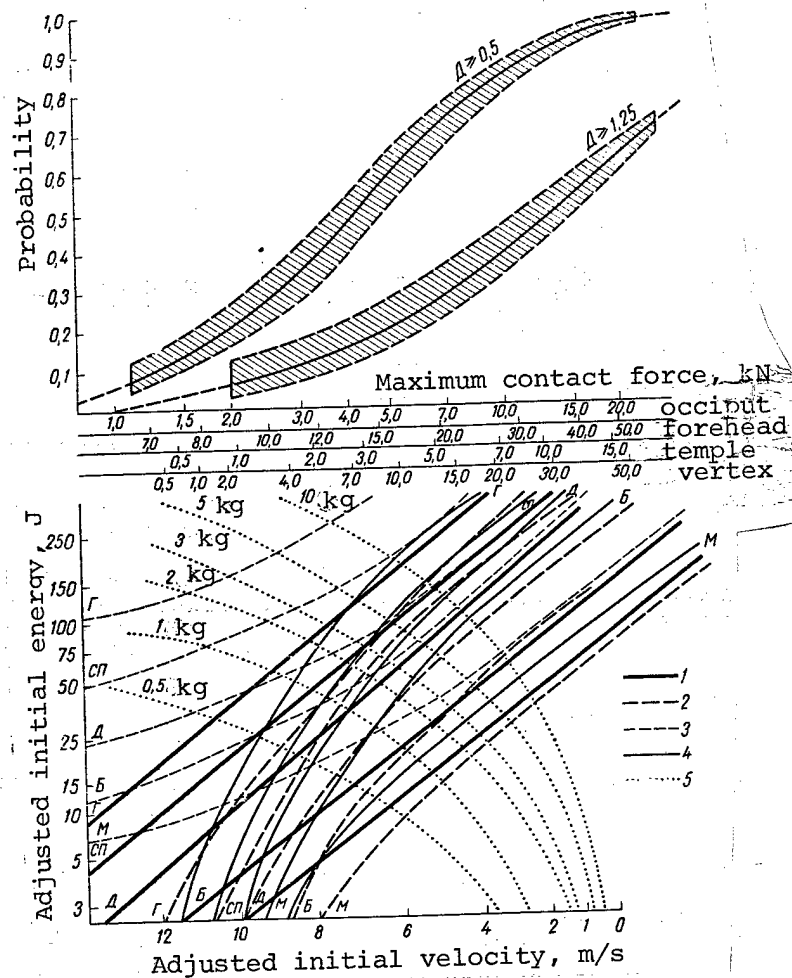


Figure 2. Correlation between impact parameters and evaluation of trauma hazard

- 1-4) blows to occipital, frontal, temporal and parietal regions, respectively
- 5) adjusted mass
- Γ) ground
- Д) wood
- Б) concrete
- М) metal
- СП) porolon coated steel

A version of the Mangust model designed for testing protective helmets is equipped with an additional soft analogue of scalp, made of synthetic fiber with a polyurethane surface, as well as scale model of the facial part of

the head, which permitted securing helmets on the models in a realistic way (see Figure 3). It should be noted that, at this stage, it was not yet possible to achieve total simulation of the local force characteristics of the scalp. Nevertheless, even in this approximation, the local force characteristics of the Mangust model conformed better to parameters of the head than the characteristics of the skull or head of a cadaver, let alone a rigid cast (Figure 4). We therefore consider that, at this stage, it is expedient to use a model of the Mangust type for evaluation of shockproof properties of pilots' helmets, while continuing to refine it with regard to simulation of integumental tissues.

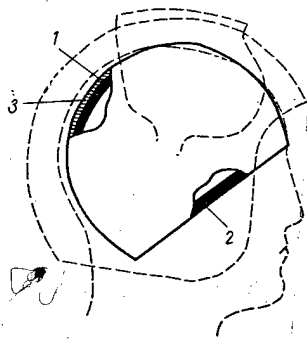


Figure 3.

Sketch of Mangust model. Dash lines show head and helmet outlines

- 1) sinciput of model    3) analogue of
- 2) base of model        scalp

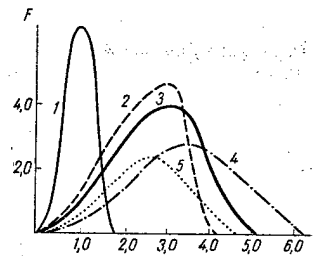


Figure 4.

Dynamics of human head and its physical models with impact load

- 1) human skull
- 2) head of biomodel
- 3) Mangust model
- 4) human head
- 5) skull + felt 8 (mm)

Use of the Mangust model to assess protective helmets made it necessary to define the criterion of trauma safety of conditions under which the head was submitted to impact. For this purpose, analysis was continued of clinical data on cerebrocranial trauma in the aspect of dependence of clinical manifestations on impact conditions. Use of a model of local head deformation upon impact made it possible to assess the parameters of the impact pulse in the case of actual cerebrocranial trauma on the basis of a description of the circumstances of the occurrence (see Figure 2) with consideration of height of fall, nature of impact surface and localization of the blow [16].

A defined parameter D (from the English word, disease) was introduced to assess the condition of victims; it takes into consideration the state of consciousness immediately after trauma was sustained (factor A), general condition the first 2-3 days after trauma (factor B), extent of general and occupational rehabilitation (factor C). Factor A was rated according to 5 gradations (counting the zero level), in view of its particular significance in determining the possibility of saving the pilot, while factors B and C were rated in 3 gradations each. The numerical value of parameter D was one-fourth the sum of factors A, B and C, i.e., it was normalized

for 2, since in this case a rating of 0 meant that there were no adverse sequelae, while 1.0 and 2.0 were the bottom and top limits of the range of inadmissible states. The D values considered inadmissible were those at which it was impossible for a pilot to perform rescue operations in an emergency situation, to survive in an uninhabited area using the resources of the portable emergency kit, or if the pilot is threatened with disability or death. Statistical processing of the clinical data in relation to physical parameters of the impact revealed that, with each given localization of impact the severity of cerebrocranial trauma is determined primarily by the maximum contact force of impact. Significant regression functions were also demonstrated between characteristics of the blow to the head and probability of occurrence of significant or inadmissible trauma. Figure 2 illustrates the curves for probabilistic forecasting of the state of victims as a function of conditions of impact with the head.

Considering the special role of deformation of the base of the skull in biomechanics of cerebrocranial trauma, one can use as a criterion of trauma hazard of impact the parameters of motion of the base of the Mangust model, calculating the link between these parameters and conditions of impact load on the top of the model. A rather simple and reliable mechanical recorder-sensor was developed for direct evaluation of the displacement of the central zone of the base of the Mangust model. There was experimental demonstration of statistically reliable relationship between deformation of the base of the model and parameters of impact pulse at the top (primarily maximum contact force). A comparison of these results to the probability curves illustrated in Figure 2 made it possible to determine the critical values of base deformation, and impact conditions (and deformation of the base) under which the probability of favorable outcome was at least 95% were considered as trauma-proof.

Thus, the set of studies involving simulation of cerebrocranial trauma in man enabled us to develop and manufacture a physical model that reflects well the biomechanics of the human head during impact, as well as to obtain a validated criterion, from the medical point of view, of trauma safety of impacts in experimental evaluation of pilot helmets.

About 300 experiments were performed by the method described above with use of the Mangust model and evaluation of trauma safety of impact according to deformation of the base of the model, in order to test some Soviet and foreign pilot helmets. This investigation was conducted on the above-described stand, using flat surfaces differing in hardness, as well as elements of aircraft cabins (headrest, glass-covered parts). As a result of this study, some distinctions were demonstrated in shock-absorbing properties of these items, so that we could compare the helmets to one another and different zones of the same helmet. Determination was made of the range of trauma-safe use of this gear. It should be noted that the demonstrated differences between the tested helmets were not found in the studies where a rigid cast of the head was used.

It can be assumed from the foregoing that, in spite of the possibility of upgrading even more the proposed method for testing protective helmets, the

version developed at the present time provides sufficiently reliable evaluation of the quality of protection of the head against impact.

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AIRCRAFT CREW DIET IN EMERGENCY SITUATIONS

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[Article by I. G. Popov]

[English abstract from source] An analysis of the arrangement of contingency nutrition of aircrew members, composition and nutrient value of emergency diets used in the USSR and other countries allows the conclusion that low-caloric (subcaloric) diets are replacing isocaloric diets. When developing contingency kits, emphasis is given to portable kits because onboard kits are often inaccessible. This is to be taken into consideration for further improvement of contingency nutrition. Specific attention is to be given to the methods of providing nutrition, maintaining metabolism and work capacity under the conditions of food and water shortage and, consequently, starvation and dehydration of the body.

[Text] The nutrition of aircraft crews following an emergency hard or splash landing in an uninhabited region (emergency diet) occupies a somewhat special place among other forms of flight crew diets. This is attributable primarily to the fact that, unlike the usual, preflight, onboard and other forms of flight personnel diets, the so-called emergency diet of crews cannot usually guarantee that pilots will be provided with adequate amounts of nutrients. In most cases, after an emergency landing (on the ground or water) it is virtually impossible to organize nutrition that would be satisfactory in quantity and quality, let alone meet the current physiological nutritional standards.

The major restrictions with regard to weight and dimensions, rigid requirements as to storage conditions and time, the specifics of food intake and, in most cases, impossibility of predicting the exact time that the crew will spend in the area of the emergency landing (hard or splash[on land or water]) make it extremely difficult to provide crews with a sufficient supply of food, affect the chemical composition of the food allowance, gustatory qualities of food, choice of foods, packaging, modes of use and other important parameters of emergency rations for flight personnel. In most cases, the existing emergency food supplies are intended only to assure crew survival in

an unpopulated area after a landing on the ground or water until assistance arrives or they are evacuated by the rescue services, or else leave the disaster area on their own [1-3].

We should also mention, as one of the distinctions of emergency rations, that there is even greater relationship between this form of nutrition and water supply than with other variants of flight crew diets. For this reason, we are often dealing with the question of providing special food and water rations for pilots for emergency use, in which there could be substantial change in proportion of fluid and food, depending on the expected climate, geographic and other conditions in the area of a possible emergency dry or wet landing. Under some conditions, when fluid loss is so great that there is a danger of rapid dehydration, for example, in arid deserts in the hot season, the presence of a sufficient amount of water could be the deciding factor in successful survival of crews. There is every reason to consider water in emergency rations as one of the most important nutrients, along with protein, fat, carbohydrates, minerals and vitamins. The chemical composition of the emergency rations, in turn, has a serious influence on fluid metabolism and fluid requirements, especially when there are limited sources of water and a strain on external fluid metabolism.

Emergency nutrition is closely linked not only with emergency supply of water, but other elements of the emergency supplies for a pilot, which, as they provide more or less favorable conditions for survival, protection against extreme environmental factors, prolong or shorten the period of searching for the disaster victims, have a definite effect on the pilots' requirements, with regard to energy, certain nutrients and water, as well as the time and schedule for consuming emergency rations.

The approach to the schedule of food and water intake under emergency conditions also requires different criteria, as compared to organizing nutrition in the situation of ordinary routine activities of flight personnel.

When setting up emergency rations, in addition to the special stock of food and water at the disposal of pilots, which is stowed in advance, it is desirable to augment and enrich the food and water allowance by means of local natural food sources (plants and animals) and water [2]. This circumstance advances several questions, which are rather complex and specific to this form of pilot nutrition, and they are related to the search for, expert evaluation, recovery, processing and optimum use of diverse representatives of the "wild" flora and fauna, in combination with the emergency food supply or without it.

The above questions, which are related to nutrition and water provisions for aircraft crews after forced dry or splash landing in an uninhabited area, have been the subject of investigation for several decades. The unwaning interest in them is attributable to the persisting danger of a forced emergency abandonment of aircraft or necessity to land the aircraft at different distances from the base airport, including uninhabited areas. The problem of emergency diet and water supplies as a whole cannot yet be considered definitively resolved. This is indicated by the constant appearance of new, more rational solutions with reference to a number of parameters. In addition,

advances in the study of low-calorie diets and starvation, as well as in biotechnology, open up new possibilities for a better solution of the problem of emergency diet and water supply, and compel us to revise old positions.

In our country, a need to provide food and water for flight personnel arose already in the 1930's, at the start of development of Soviet aviation. In 1932, F. G. Krotkov [4] briefly mentioned that 3-day supplies of canned food and water are being provided on aircraft in case of accident or forced landing. The energy value of the daily food allowance was estimated at 2615 kcal [4, 5]. We were unable to find a more detailed physiological and hygienic description of these early emergency food and water rations. In one of the first Soviet manuals on aviation hygiene by G. M. Popov, he does not even mention emergency diet as a special form of diet for flight personnel [6]. However, already in 1936, F. G. Krotkov singles out emergency rations as a separate, specific type of nutrition for flight crews that requires the attention and supervision of aviation physicians, in a chapter dealing with flight crew nutrition [7]. The new unified "food supply in aircraft," introduced for flight personnel in 1936, was intended to provide food for aircraft crews in case of accident or forced landing in areas far removed from inhabited localities, as well as for stopovers. There were provisions to furnish one of two versions of food supplies, depending on the conditions along the route of the flight [7, 8].

When flying over Siberia, the Far East and other relatively uninhabited regions of the USSR, as well as over seas and oceans, the food supplies provided for meals for 3 days and contained somewhat more items. The daily assortment of foods for such a 3-day supply included 300 g biscuits of the "cracker" type, 300 g "Gold Label" [Zolotoy yarlyk] chocolate, 1 can (net weight 338 g) of "braised meat." In addition, 1000 g of water was issued for each day. Consequently, for the 3 days, each aircraft crew member was issued an emergency food allowance consisting of 900 g crackers, 900 g "Gold Label" chocolate and 3 cans (1014 g net weight) of "braised meat" and 3000 g water.

For flights in other regions of our country, where help could be rendered faster and there is a higher density of urban areas, the food supply is intended for 2 days. The daily assortment of foods for the 2-day food supply consisted of 300 g crackers, 200 g "Gold Label" chocolate, 1 can of meat (in this case, "Boiled Meat" or "Roast Meat," or "Salt Meat" cans were issued, with net weight of 260 g). Water was issued at the rate of 800 g/day. Consequently, for 2 days spent in an emergency situation, each member of a flight crew was issued the following rations: 600 g crackers, 400 g chocolate, 2 cans of meat (net weight 520 g) and 1600 g water.

Intake of the food supply was allowed in all cases of accident or forced landing in remote places no sooner than 4 h from the time of landing. Apparently, it was considered that one could use the on-board rations 3.5 h after taking off for a long-term flight.

The above variants of food supplies were issued to each crew member before take-off. Before the flight, they were stored at the airport close to the location of the aircraft. Proper packaging prevented spoiling of the food when stored at the airport and aboard the aircraft. Storage time

for the food supplies was set at 6 months for crackers, cookies and chocolate and 1 year from the time of processing for canned meat [5, 7]. Before a flight, fresh water had to be used to fill containers, and it was mandatory to discard it after a flight.

Even then, serious attention was given to the need for medical supervision of organization of emergency rations. The food supply had to be inspected once a month by a physician, who prepared a certificate on the results of this inspection. Foods that did not last for the established storage time had to be replaced with fresh items. Items for which storage time had elapsed, but were fit for consumption in the physician's opinion, could be used for regular meals, instead of other items contained in the standard daily food allowance on the ground, in accordance with the established norms for food substitution [7]. For example, 55 g of crackers could be used instead of 100 g wheat bread and 100 g chocolate instead of 1/3 of a can of condensed milk. Interestingly, even then, chocolate was not considered suitable for all conditions of storage and use of emergency rations. F. G. Krotkov wrote in 1936 that "in the summertime, it is desirable to replace chocolate, which melts at high temperatures, with dry cocoa and condensed milk" [7].

S. S. Kholin [8], who headed the work on developing the first emergency rations at the Institute of Aviation Medicine imeni Academician I. P. Pavlov, gave the following estimate of the nutritional value of the daily assortment of foods contained in the "Food supplies to be used in cases of forced emergency landings far from populated regions." According to the calorie tables of that time, the daily allowance in the 3-day version of the food supplies constituted 3052 kcal, 102 g protein, 125 g fat, 360 g carbohydrates and 1000 g water. Overall weight of the daily rations in this version of the food supplies constituted 940 g and, counting the water, 1940 g. The nutritional value of the entire 3-day supplies is as follows: 9157 kcal, 307 g protein, 376 g fat, 1079 g carbohydrates (according to nutritional value tables of that time). Overall weight of the food supplies for 3 days was 2820 g and, counting the water supply, 5820 g.

Judging from the above figures for nutritional value, the emergency rations adopted for aviation in 1936 can be rated as consisting of adequate calories and nutrition, not only for emergency situations, but everyday life. Indeed, at that time, daily expenditure of energy by soldiers in the Red Army constituted 3500-4200 kcal, depending on the type of work, while the basic Red Army rations, which flight personnel also received, contained 3634 kcal [5]. The emergency supplies also had good indicators with regard to the basic nutrients. The basic ration issued to pilots in those days contained 124 g protein, 64 g fat and 618 g carbohydrates [5].

As compared to this ration, the emergency supply contained somewhat less protein, half the amount of carbohydrates, but twice the amount of fat. This increase in fat content of the ration was related to the desire to reduce the size of the emergency kit with retention of high caloric value. It should be added, that the food standards of Voigt used at that time for moderately heavy work recommended 118 g protein, 56 g fat, 500 g carbohydrates for a total of 2748 kcal per day, while the Rubner standards called for 127 g protein, 52 g fat, 509 g carbohydrates for a total of 2871 kcal [5].

Thus, the emergency food kit of 1936 could hardly be considered a low-calorie diet for physical work of moderate heaviness with use of the first version for 3 days and the second for 2 days. It would be more correct to rate it as an isocaloric diet.

The structure of nutritional value of the daily emergency rations for a 3-day emergency situation is as follows, according to the data of S. S. Kholin [8]: The "Cracker" biscuits (300 g) constituted 4079 kcal, protein 33 g, fat 28 g and carbohydrates 167 g. The "Gold Label" chocolate (300 g) constituted 1344 kcal, containing 13 g protein, 54 g fat and 193 g carbohydrates. The "Braised Meat" in cans (1 can, net weight 340 g) constituted 639 kcal, with 56 g protein, 44 g fat and no weight given for carbohydrates. The levels of other nutrients are not given. Probably no standards had been set for them. According to the caloric value and composition of this food supply, its developers tried to cover the energy expenditure of pilots based on moderate work after emergency landing.

It was stressed that aviation conditions require that the food kit aboard aircraft be exceptionally portable, small in dimensions and in weight of items in it, and that it be planned for a limited number of days [8].

Aviation practice with respect to use of the food supplies aboard aircraft generally confirmed their hygienic efficacy in cases of emergencies and forced landings in regions far from populated areas. For this reason, in a routine revision of the physiological standards for flight personnel diet, the first emergency food kit developed by S. S. Kholin and adopted in 1936 was retained without changes and adopted in the form of special norms of daily food supply for each space in the aircraft. As before, two versions of the food kit were issued, depending on the climate and geographic region of flights. At the same time, it was permitted, when necessary, to augment the food supply in aircraft in accordance with flight duration and other conditions. It was confirmed that strict medical supervision was necessary of the quality of food items in emergency rations [9, 10, 19].

At the same time, work continued to further develop emergency diets. In 1939, as a result of the studies conducted under the guidance of V. V. Levashov [11, 12], an emergency food supply (ES) was added for crews of multi-passenger aircraft and passengers, to be used in case of forced landing in an uninhabited area or of some special problem on passenger lines. The ES was planned for 2 days. Overall weight of the daily allowance per person was 1132 g (net). It contained the following dry, concentrated and preserved items: 1) dry foods--"Military march" biscuits, cookies, "Kola" chocolate, sugar, tea, salt; 2) preserved items--chipped liver or braised meat, tongue, condensed coffee with milk; 3) concentrates--pea soup-puree, Ukrainian borshch, buckwheat, noodle casserole [or pudding], cranberry pudding. The norm for drinking water provided for 1 liter of water per person per day aboard the aircraft. In Central Asia, this supply had to be increased to 2 liters/day. The total amount of water was planned for use for 2 days of an emergency situation, as the supply of food. The water was to be stored in thermos bottles, and in the winter they had to be filled with hot water, with temperature not exceeding 55°C. In the

absence of water to prepare food, it was recommended that items be used that were ready for consumption. Their number in the ES was planned so as to maintain the health status and work capacity of an adult person for 48 h with performance of moderate work. In the case of a forced landing, the ES packages could not be opened sooner than 4 h after the landing. In addition to the foods and water, the ES also included dishes for preparation of hot food and place settings. The nutritional value of one ration from the ES had to provide for the health and work capacity of an adult person for 48 h, even if heavy physical work was involved. According to the data of V. V. Levashov, the daily food allowance contained 137 g protein, 65 g fat, 706 g carbohydrates, with a total of 4070 kcal. It was recommended that the daily allowance be divided into three parts, scheduling 3 meals: breakfast (1166 kcal), dinner (1809 kcal) and supper (1023 kcal) per person on the 1st day. The shelf life of the ES was 9 months. Unfortunately, it was not possible to find in the literature sources any information about the results of physiological and hygienic evaluation of the emergency supplies in question, either under experimental laboratory conditions or in simulated emergency situations, or any data about the dynamics of nutritional status when using emergency rations in different climate and geographic zones.

A standard emergency ration was introduced with the start of the Great Patriotic War, in autumn of 1941, for all aircraft on the front lines and in the rear, regardless of flight duration and climate-geographic zone. The new food kit "in case of emergencies and forced landings" was issued to each aircraft crew member and consisted of the following items: 3 cans of condensed milk, 3 cans of meat, 800 g of crackers, 300 g chocolate, 400 g sugar. It was allowed to replace the 300 g of chocolate, if none was available, with 800 g cookies. According to this list, the emergency supplies included only items that could withstand long-term storage and had high nutritional value with relatively small size and weight. All of the items could be consumed without additional cooking or warming.

The emergency kit had the following nutritional value: 12,190 kcal, 396 g protein, 407 g fat and 1653 g carbohydrates [13]. It was believed that this nutritional value of the emergency kit should meet entirely a person's food requirements for 3 days and, if necessary, longer. Indeed, with use of this food supply for 3 days, the victim of an accident had a daily food allowance with the following nutritional value: about 4063 kcal, 132 g protein, 136 g fat and 551 g carbohydrates, which is enough for moderate or heavier daily physical loads. Consequently, at least an iso-calorie diet, and not a low-calorie one, was planned for emergency situations.

The emergency food supply of 1941 was stowed aboard the aircraft and was, in essence, the onboard emergency supply (BAZ). But even in those years, it was necessary to pack the emergency kit in the pilot's gear in some cases: belt, parachute straps, etc. A modification of the emergency kit also appeared. In particular, the following version of a portable emergency kit was recommended, which totaled 1750 kcal: 300 g chocolate (including 100 g of "Kola" chocolate), 100 g "meat-borshch" concentrate, 100 g alcohol, 1 box of matches, 2 packs of cigarets. Overall weight of the kit was 750 g. Attention was given to the need of monthly inspection of the condition of the emergency supplies and, in the warm season, this had to be done twice

a month. Shelf life was set at 6 months for cookies and chocolate and up to 1 year for canned meat.

In the early postwar years, the wartime BAZ continued to be used on all types of aircraft. The weight of cans with condensed milk and meat was standardized and defined as 410 g and 338 g, respectively. In the absence of chocolate it was allowed to replace it with sugar as follows: 375 g sugar in the place of 300 g chocolate. As in prior years, when it was allowed to use cookies instead of chocolate, such substitution was validated by operational requirements. Unfortunately, we were unable to find in the literature any physiological and hygienic substantiation of the nutritional value of the emergency kit of that time or results of their experimental evaluation.

Studies to upgrade the diet of flight personnel in emergency situations continued, and in 1956 a new version was proposed for emergency food for pilots to be used after a forced landing or landing on water in an uninhabited area. As a result of analysis of the cases of flight crew survival after forced dry or splash landing, it became increasingly important to provide for effective, portable, small-sized emergency supplies (NAZ), which also included a supply of food, in addition to the BAZ.

For this reason, it was logical for the "emergency food kit for aircraft crews" developed under the supervision of G. A. Arutyunov and adopted for use in aviation in 1956 to consist of two parts: NAZ in a special pack and BAZ. The NAZ, together with drugs and essential items, was in a special, flat, small container which was stowed in the pilot's ejection seat, so that it would be handy to the victim after a parachute drop. It contained "boiled meat in its own juice" in tin cans, each weighing 100 g, with a total of 300 g; "Pokhod" [march] biscuits in packages of 60 g each, packed in plastic film, with a total of 240 g; 100 g cheese in a No 1 tin can; refined lump sugar, in packets of 15 g, total 300 g; 15-g chocolate bars in aluminum foil, total 300 g; 50 g table salt packed in polymer film. The NAZ contained only items with a long shelf life and suitable for consumption both with and without warming. Total nutritional value of the food in the NAZ constituted the following, according to calorie tables of that period: 4654 kcal, 141 g protein, 180 g fat, 701 g carbohydrates, the net weight totaling 1240 g. Protein constituted 12.4% of the total calories, fats were 35.9% and carbohydrates 51.7%. The proportion of protein, fat and carbohydrates in grams was 1:1.25:4.22.

Development of this NAZ was based on the principle of preserving not only life, but work capacity for 3 days. It was believed that, for this time, the pilot involved in the accident would be able to withstand the rigorous ambient conditions, watch the situation actively and send signals about his location to the search groups of the rescue service.

The NAZ provided for intake by the pilot of 47 g protein, 60 g fat, 234 g carbohydrates, with a total net weight of about 413 g and caloric value of about 1550 kcal for each of 3 days in an emergency situation. This was known to be less than the energy expended in an emergency situation, particularly under rigorous climate and geographic conditions when there is greater expenditure of energy due to performance of the necessary steps



for survival under difficult conditions. In turn, extreme ambient climate factors require a greater expenditure of energy during the intensive function of physiological adaptation mechanisms. This emergency ration in the NAZ provided for maintaining only minimal work capacity in pilots who have been involved in the accident, when used for 3 days.

Consequently, the new NAZ, introduced as equipment in 1956, already provided for a low-calorie (subcalorie) diet, rather than isocalorie, for use for 3 days, unlike the NAZ and BAZ of the earlier period. With use of the 1956 NAZ, it was inevitable for there to be gradual development of signs of quantitative and qualitative undernourishment. Such a serious change in physiological and hygienic capabilities of the NAZ was attributable primarily to the relatively small size and weight allowed for the food supply in the NAZ. In our opinion, there was also another reason, namely that only ordinary food items with their inherent nutritional value were used to outfit the NAZ, rather than food mixtures with considerably higher caloric value, for example, pemmican, that were specially developed for emergency situations. Evidently, the requirement that the foods from the NAZ be used in regular meals after being stored also played some role.

The tests made by G. A. Arutyunov, G. G. Gazenko, Ye. Ya. Shepelev, V. A. Petrovykh, N. P. Tendetnikov, Yu. F. Udalov, V. G. Volovich and others in the temperate climate zone, polar region, Karakum Desert and at sea established that the emergency rations in question provided for 2-3 day survival of aircraft crews after an emergency hard or splash landing. These researchers concluded that work capacity of the pilots remained at a level required for survival conditions. They also concluded that for survival in the desert for 3 days, a diet with the usual proportion of basic nutrients (protein, fat and carbohydrates), as recommended at that time for a healthy person under ordinary living conditions, was quite adequate. No doubt, the opinion of the former director of the Institute of Nutrition, USSR Academy of Medical Sciences, O. P. Molchanova, that the emergency rations per day should be made up on the basis of the usual proportion of basic nutrients had a strong influence on adoption of such an approach to the nutritional formula for emergency rations in those years. A positive effect could not be demonstrated from increasing fat or carbohydrate content of the emergency rations. For areas with a cold climate, it was recommended that the overall nutritional value of the emergency rations be increased, primarily their caloric value, since the search for crews involved in the accident could last over 3 days because of the difficult meteorological conditions. It was also stressed that it was necessary to have heating means to prevent rapid and deep cooling of the body.

Special attention was given to the need to add water to the emergency rations for deserts with a hot climate. Moreover, a sufficient supply of water at high ambient temperature was justifiably deemed the main protection against overheating and dehydration. A considerable supply of water is required to survive in the desert at ambient temperatures of 40-44°C, even if the pilot is relaxed and under the shelter of his parachute: 7 l of water are needed for 2 days and up to 12 l for 3 days.

In the case of splash landing, in the opinion of researchers of that period, conditions were often created that resembled, in several respects, those of an arid desert, but at lower ambient temperature and higher humidity. For this reason, to assure survival at sea or in the ocean, an additional supply of water was needed, while the food items must not enhance thirst and dehydration. At sea, as in the desert, the primary danger is intensive dehydration of the body, which rapidly leads to hyponatremia, which determines, to a relatively greater extent than food, the dynamics of physical condition and survival time in these conditions. Considering the results of experiments conducted in southern and northern regions, it was recommended that the emergency rations include at least 1 l water per person per day, to assure a supply of drinking water for pilots for 3-4 days spent in life-saving jackets or other gear. Thus, the water supply was recommended with increasing insistence for inclusion in the NAZ as a mandatory component, along with emergency food rations, particularly in case of landing in the desert or at sea.

It was recommended to use, if possible, the BAZ in addition to the NAZ in order to prolong flight crew survival time under emergency conditions, with retention of satisfactory work capacity for up to 6 days. The BAZ food supply was to be packed in waterproof bags and placed in appropriate parts of the aircraft cabin or rescue equipment (boats, rafts), which was to be ejected automatically from the aircraft at the moment it was abandoned by the crew.

The emergency rations contained in the 1956 BAZ consisted of the following items: 100 g tins of "boiled meat in its own juice," total 400 g; "Pokhod" biscuits in 125-g packages, total 500 g; pasteurized cheese in tin cans, 100 g each, total 400 g; condensed milk with sugar in 125-g cans, total 500 g; refined lump sugar in 15-g packets, total 200 g; table salt 50 g, in a polymer film packet. Total nutritional value of the rations in BAZ constituted 6290 kcal, with 280 g protein, 187 g fat and 831 g carbohydrates, weighing a net total of 2000 g. Protein constituted 18% of the total calories, fats were 28% and carbohydrates 54%. The proportion of proteins, fat and carbohydrates in the BAZ, in grams, was 1:0.7:2.6. Consequently, as compared to the NAZ, the BAZ contained relatively less fat and carbohydrates, but more protein, although the absolute amounts of all these nutrients were greater. Analysis of the proportions of basic nutrients in the NAZ and BAZ leads to the conclusion that their developers tried to retain proportions that are close to those that are optimum for heavy physical labor in the emergency rations, particularly the NAZ. The BAZ had a higher nutritional value than the NAZ, both in calories and in amounts of protein, fat and carbohydrates. Whenever it was possible to use the foods from the BAZ, in addition to the food items in the NAZ, pilots could improve their emergency diet considerably for 3 days or extend survival time to 6 days. Indeed, the overall nutritional value of the NAZ and BAZ rations was as follows: 421 g protein, 367 g fat, 1542 g carbohydrates, totaling 10,944 kcal and with a net weight of 3240 g. When the emergency rations in the NAZ and BAZ kits were to be used for 6 days, the daily allowance had to contain 70 g protein, 61 g fat, 257 g carbohydrates totaling 1824 kcal, with net weight of 540 g. Consequently, with such use of emergency rations, the pilots were to receive an allowance with higher nutritional value for 6 days than with use of NAZ alone for 3 days. But, in this case, too, for an emergency situation lasting 6 days, the daily allowance was low in calories (subcaloric). It is only with the combined use of NAZ and BAZ for 3 days, when the nutritional value of the daily food

allowance would increase and constitute 140 g protein, 122 g fat, 514 g carbohydrates totaling 3648 kcal, that the emergency rations would reach the isocalorie level, with retention of physical loads of pilots in the range of light and moderate work. It was confirmed in several works of those years that the pilot's emergency rations included high-calorie items and could provide for nutrition for 3-5 days in an emergency [14].

In the next years, aviation practice confirmed the need to also have NAZ of small dimensions, along with onboard emergency supplies. For this reason, "portable emergency rations for aircraft crews" and "onboard emergency rations for aircraft crews" began to be used as self-contained emergency kits since 1961. The assortment of items contained in these NAZ and BAZ was the same as in the emergency rations adopted in 1956. As for their nutritional value, after conversion with consideration of the new indicators of nutritional value of foodstuffs introduced in that period, according to which the diet of flight personnel was evaluated, somewhat different indicators of nutritiousness of emergency rations began to be cited in the literature. The "portable emergency rations for aircraft crews" (1961) contained 129 g protein, including 86 g animal protein, 153 g fat, including 58 g animal fat, 623 g carbohydrates, 4506 kcal (net), 1105 mg potassium, 79 mg magnesium, 1048 mg calcium, 2158 mg phosphorus, 23.4 mg iron, 16.5 µg cobalt, 0.19 mg vitamin A, 0.09 mg B<sub>1</sub>, 0.4 mg B<sub>2</sub>. This NAZ was indented for use for 3 days. Consequently, the daily allowance for a pilot in an emergency situation, consisted of 1502 kcal, with 43 g protein, 51 g fat, 207 g carbohydrates, 368 mg potassium, 719 mg phosphorus, 349 mg calcium and small amounts of other nutrients. This provided for a low-calorie diet, even with minimal physical loads. The "onboard emergency rations for aircraft crews" (1961) consisted of the following: 267 g protein, including 200 g animal protein; 190 g fat, including 167 g animal fat; 810 g carbohydrates, 6183 kcal (net), 3153 mg potassium, 335 mg magnesium, 4564 mg calcium, 5070 mg phosphorus, 32.2 mg iron, 70 µg cobalt, 0.91 mg vitamin A, 0.66 mg B<sub>1</sub>, 3.6 mg B<sub>2</sub>, 13 mg C, 2.5 mg PP. So that with the BAZ the pilots could receive an additional 2061 kcal, 89 g protein, 63.3 g fat, 270 g carbohydrates, 1031 mg potassium, 1690 mg phosphorus, 1521 mg calcium, small amounts of vitamins A, B<sub>1</sub>, B<sub>2</sub>, C, PP, as well as other nutrients, per day for 3 days, in addition to the NAZ. In this case, the emergency rations would become an isocalorie diet for performance of light and moderate work. The BAZ could, of course, be also used on its own, after using up the NAZ, which would prolong the time of survival conditions for another 3-4 days, but then as a low-calorie (subcalorie) daily allowance with gradual development of qualitative and quantitative starvation, even with insignificant energy expenditures.

However, the above-described emergency rations did not conform entirely to the increasing diversity of their storage conditions on different types of aircraft and use in emergency situations. The intensive development of jet aviation made it necessary to develop primarily NAZ to be placed in the ejection seats, which would be handy to pilots after landing (on land or water) by parachute. Because of the fact that, in most cases, it is impossible to land jet aircraft anywhere but an airport, use of the old type BAZ became extremely limited. For this reason, in addition to the two existing variants of emergency rations that we discussed above, an NAZ was developed, in which there was a somewhat different assortment of foods, and used starting in 1963 for flight personnel of aircraft equipped with ejection seats. It contained

the following: 100-g tin cans of meat, total 400 g; 30-g packages of "Pokhod" biscuits, total 90 g; 15-g packets of sugar, total 135 g; 100-g bars of chocolate, total 300 g; table salt in a polymer film packet, total 60 g. The same types of items were used in this NAZ as in those introduced in 1956 and 1961, but in somewhat smaller quantities of some items. The nutritional value of this NAZ, which we estimated on the basis of tables of nutritional values of foodstuffs adopted in 1965, was as follows: 121 g protein, including 86 g animal protein; 152 g fat, including 58 g animal fat; 448 g carbohydrates, 3745 kcal (net), 1065 mg potassium, 2077 mg phosphorus, 1028 mg calcium, 59 mg magnesium, 22.2 mg iron, 15 µg cobalt, 0.19 mg vitamin A, 0.09 mg B<sub>1</sub> and 0.4 mg B<sub>2</sub> [1].\* This NAZ, as its precursors, was designed for 3-day use. Consequently, the daily allowance had to have a caloric value of about 1249 kcal, with 40 g protein, 51 g fat, 149 g carbohydrates, 355 mg potassium, 692 mg phosphorus, 19 mg magnesium and 342 mg calcium. Such nutritional value could provide for only a subcaloric diet for 3 days of an emergency situation. Of course, the items in this NAZ did not contain a sufficient amount of vitamins, minerals and trace elements, as was mentioned by some authors [16]. This NAZ included a supply of water. In developing the new NAZ, as before, preference was given to an allowance with the optimum protein, fat and carbohydrate content for ordinary living conditions.

Starting in 1967, a unified assortment of emergency rations again began to be used for flight personnel under emergency situations, without strict separation into BAZ and NAZ. In addition to this kit, the NAZ introduced in 1956 continued to be used. The separation of the emergency outfit into NAZ and BAZ was to be made locally, depending on the types of emergency kits and convenience of placement in the aircraft. This was decided because a strictly regulated separation of the emergency outfit into NAZ and BAZ, which was made in 1956-1961, could not take into full enough consideration all of the possible variants of placing emergency supplies in existing and new types of aircraft, as well as conditions for stowing in parachute systems, ejection seats and in the pilot's gear. The latitude afforded locally for use of the emergency kit containing a significant amount of various food items differing in size and packaging made it easier to find the optimum solution in each individual instance. This emergency supply kit, along with drugs, dressings, water flask, flashlight and essentials, contained an assortment of foods: 100-g cans of "boiled meat in its own juice," total 700 g; pasteurized cheese in 100-g cans, total 500 g; "Pokhod" biscuits in 60- and 125-g packages, total 740 g; condensed milk with sugar in 125-g cans, total 500 g; sugar in 15-16-g packets, total 500 g; 15-g chocolate bars, total 300 g; salt in 50-g packets, total 100 g.

According to our data, the nutritional value of these emergency rations, which was determined by calculation with consideration of the nutritional value of the different items adopted in 1965, was as follows: 10,689 kcal, 396 g protein, including 286 g animal protein; 343 g fat, including 225 g

\*Somewhat different data are cited in some works [15, 16]: 3777-4506 kcal, 121-129 g protein, 86-152 g fat, 598-625 g carbohydrates, as well as 126.7 g protein, 159.6 g fat and 348 g carbohydrates [2].

animal fat; 1433 g carbohydrates, 4258 mg potassium, 7228 mg phosphorus, 414 mg magnesium, 6118 mg calcium, 55.6 mg iron, 86.5 mg [sic] cobalt, 1.1 mg vitamin A, 0.75 mg B<sub>1</sub>, 4 mg B<sub>2</sub>, 13 mg C and 2.5 mg PP. Such an emergency rations kit when used for 3 days could provide an isocalorie diet with mild physical work. It is another matter that the part of it contained in the BAZ could not be used always by far.

In those same years, experience made it necessary to use extremely small NAZ, which were stowed in the parachute system or pilots' clothing. In such NAZ, the food supply was also very limited. An example of such an NAZ is the kit in which emergency rations consisted of only 300 g chocolate and 60 g table salt. This NAZ, like the others, was intended for 3-day survival and subsequently even 5 days [3, 17, 18]. The nutritional value of 300 g of chocolate fluctuates somewhat, depending on the fat and sugar content, ranging for example, from 540 to 557 kcal/100 g according to energy value [17].

The nutritional value of this NAZ, when furnished with the very popular "Sport" chocolate (GOST 65-34--69) is characterized by the following figures: 1671 kcal, 22.8 g protein, 111.6 g fat, 152.4 g carbohydrates, 1335 mg potassium, 231 mg sodium, 105 mg magnesium, 645 mg calcium, 3.9 mg iron, 0.18 mg vitamin B<sub>1</sub>, 0.87 mg B<sub>2</sub>, 678 mg P and 1.14 mg PP [17]. Consequently, in an emergency situation, when this NAZ is used for 3, let alone 5 days, pilots can expect to be on a low-calorie diet with energy value of about 557 and 334 kcal/day, respectively, depending on the indicated survival time.

Physiological and hygienic assessment of the dynamics of nutritional status and general health and work capacity, with experimental use of this emergency food supply in a temperate climate, as well as with replacement of 300 g chocolate with beet sugar with the same weight, led to the conclusion that such a low-calorie NAZ is permissible for use for 3-5 days. The changes in nutritional status were moderate with physical loads of 3000-3200 kcal/day, and there was rapid recovery [3, 17, 18, 19].

Since most modern aircraft are subject to severe destruction in case of an emergency landing, use of BAZ by crews who landed separately with parachutes is growing increasingly difficult or simply impossible. For this reason, efforts have been made in the last decades to provide the crews of aircraft that have been subject to a disaster with emergency rations as part of the floating rescue gear, special parachute containers, etc., that should separate automatically from the aircraft in case of accident, in addition to the portable NAZ that are dropped to the ground on the parachute system together with pilots. Consequently, the aircraft crews could, under favorable conditions, also use the emergency rations from the above rescue equipment, which replace, so to speak, the old BAZ, in addition to the individual NAZ, in the region where they have made a hard or splash landing.

At the present time, there has been maximum development of floating lifesaving equipment, for example, inflatable rafts (PSN-6 and others) and inflatable aviation boats (MLAS-1, LAS-5 and others) which are usually supplied with food and water [2, 20]. As an example, we can mention the emergency food in the LAS-5 lifeboat, which consists of 3 rations each containing the following: 400 g canned meat (in 100-g cans), 180 g "Pokhod" biscuits (in

60-g packages), 150 g sugar (in 15 g packets), 300 g chocolate (in 15-g bars) and 60 g table salt. If we compare the assortment in these emergency rations to the BAZ used in 1956, it is easy to see that virtually the same items were used in both instances, but in somewhat different amounts.

According to our data, the emergency rations per person for the entire time spent in an LAS-5 has the following nutritional value: 128 g protein, 148 g fat, 436 g carbohydrates for a total of 3688 kcal; 2715 mg potassium, 1586 mg phosphorus, 164 mg magnesium, 418 mg calcium, 0.26 mg vitamin B<sub>1</sub>, 16.7 mg B<sub>2</sub> and 9.14 mg PP. The calculations were made using the tables of nutritional value in effect in 1965 for evaluation of pilot diet. "Boiled beef in its own juice" was used as the canned meat. As shown by the submitted data, use of this emergency supply could provide only a low-calorie diet for 3 days, but combined with the items in the NAZ, the pilots' diet could be improved appreciably. The unlikeliness of using the BAZ of modern aircraft was one of the reasons for discontinuing to stow them in aircraft. At the present time, aircraft crews are provided only with different types of NAZ, which contain relatively small emergency assortments of foods, as well as emergency rations in lifesaving equipment. All this emergency food supply usually provides only for a subcalorie diet for pilots, when used for 3-5 days.

Questions of emergency rations for aircraft crews also have a rather long history in other countries. Analysis of data in the literature leads us to conclude that, in each concrete instance, emergency supplies as a whole, including food rations, were the result of a certain compromise, due to the actual conditions under which they were used. Requirements as to permissible weight and size, climate and geographic conditions in the region of emergency survival and its duration, capabilities of the rescue service played a special role.

In outfitting emergency kits, several researchers adhered to the requirement that the rations contain all of the basic nutrients in optimum or, at least, wise proportion. For example, the English emergency rations for arctic regions that were to last for 3 days contained 0.68 kg protein and fat (2034 kcal) and 1.36 kg carbohydrates (4771 kcal) [22]. The "Winter" 3-day arctic rations of the German Air Force during World War II consisted of diverse items: canned ham, rusks, chocolate, bouillon cubes, sugar, dextrose tablets totaling 11,450 kcal [23]. The parachute emergency kit consisted of soybean and meat concentrates, chocolate and dextrose tablets totaling 3750 kcal [23]. The American SA-4 arctic emergency rations consisted of bread and cheese cakes, jello, marmelade, chocolate and powdered cream, totaling 2100 kcal [24, 25]. Another version of these rations, SA-3, contained 1796 kcal and consisted of chocolate, fruit and bread concentrates, marmelade, packets of powdered beverages [26]. The unified rations of the English Air Force, Mark-5, consisted of an A unit totaling 4387 kcal, with a 1:2.97:6.94 ratio of proteins, fat and carbohydrates, as well as a B unit, totaling 1950 kcal, with a 1:1.97:2.27 ratio of the same nutrients [27]. Summarizing the most recent research, S. Nil and R. Shamburek wrote: "In order to survive in an uninhabited region, a person should receive at least 2000 kcal per day in the form of food containing 15% protein, 52% carbohydrates and 33% fat, with at least 1 l of water on cool days and 3 l on hot days." Survival time was not indicated [28, 29].

In the last decades, emergency rations have also appeared that are intended primarily for situations where there is not enough drinking water, which contain mainly carbohydrates. For example, the ST rations for U. S. pilots in the tropics and temperate climate, with a water shortage, consisted mainly of carbohydrates and constituted 1700 kcal for 3 days [26, 30]. The C-1 rations (United States), which are kept in gear pockets, consisted of marmalade and starch cakes, as well as dehydrated beverages, and constituted 860 kcal [26]. The Dutch emergency rations for naval pilots consisted of 760 g cake flour concentrate and 350 g of glucose in tablets [31].

This survey of development of problems of emergency rations indicates that the desire to organize adequate nutrition and water supply in emergency situations that would meet the pilots' requirements as to nutrients and water has virtually always encountered serious limitations due to a number of technical and sanitary requirements. As a rule, emergency rations acquired the form of a low-calorie (subcalorie) diet, by virtue of the fact that they became increasingly limited to the possibility of using items only from the small NAZ, since the BAZ become increasingly unusable after an emergency landing. Development of universal NAZ for all types of aircraft and climate-geographic zones turned out to be extremely difficult. For this reason, a number of variants of NAZ have a specific purpose as to region and time of use.

Further improvement of emergency rations depends to a significant extent on investigation of metabolic distinctions in the case of a low-calorie diet and dehydration under different survival conditions, as well as development of means of maintaining fluid-salt metabolism, determination of optimum schedules for using limited supplies of food and water in different emergency situations with due consideration of how the body's energy resources are expended, a search for optimum food items and artificial mixtures of nutrients, development of effective methods of conditioning crews for survival when there is a shortage of food and water. As before, questions of finding food and water in local resources, as well as optimum means of using them together with NAZ, are pressing.

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EXPERIMENTAL AND GENERAL THEORETICAL RESEARCH

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CHANGES IN CARDIAC OUTPUT AND ORTHOSTATIC STABILITY OF COSMONAUTS

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[Article by P. V. Vasil'yev, A. D. Voskresenskiy, V. G. Doroshev, V. V. Kalinichenko, N. A. Lapshina and V. V. Shchigolev]

[English abstract from source] Examinations of 14 cosmonauts who performed orbital flights of 14 to 175 days were used to correlate cardiac output (CO) inflight with orthostatic tolerance and LBNP reactions postflight. In 3 crewmembers CO was lower than or close to the preflight level. In 4 cosmonauts CO was higher than preflight. The remaining 7 crewmembers showed lower orthostatic tolerance and stronger LBNP reactions. The difference between mean CO values before and during flight was in negative correlation with orthostatic tolerance ( $r = -0.6$ ) and in positive correlation with LBNP reactions ( $r = 0.7$ ). The correlation coefficients were derived from small samples but an identical relationship between the two different tests with inflight CO variations gives evidence that such a relationship actually exists.

[Text] During long-term spaceflights there is both increase and decrease in resting minute volume (MV [cardiac output]) [1, 2]. The question arises: Is this difference in directions of change in MV related to individual distinctions of adaptation to flight conditions? If this is so, it could be expected that these individual differences would also be manifested in the course of readaptation to earth's gravity. An effort was made here to assess the relationship between inflight changes in MV, orthostatic stability and reactions to lower body negative pressure (LBNP) test on the first few post-flight days.

Methods

We collected for analysis the results of examining 14 cosmonauts who had participated in spaceflights lasting 14 to 175 days. MV was determined by calculation, from the polycardiographic and tachooscillographic tracings [3-5]. Individual ranges of variation and individual mean MV at rest were determined from the results of the tests made in the period of preflight training. These characteristics were then used to classify inflight MV changes. The numerical

expressions of individual MV reactions were found as the difference between mean inflight and preflight values ( $\Delta MV$ , in  $\ell/\text{min}$ ). The found values for  $\Delta MV$  were compared to the overall ratings of orthostatic stability and reactions to LBNP test in the 1st week after the flight. We used a previously developed [6] integral indicator of orthostatic resistance (IIOR) as the general numerical evaluation of the orthostatic test. This indicator is based on the use of empirical scales, which make it possible to express changes in different physiological parameters during the passive orthostatic test on the same rating scale. Higher grades for IIOR correspond to greater orthostatic stability. The values of a linear discriminant function (LDF), previously found from a sample of preflight and postflight cases [7] served as the general rating of reactions to LBNP. This LDF characterizes best the differences between preflight and postflight reactions to LBNP according to a set of physiological parameters. Higher LDF values correspond to a higher probability that a given instance is referable to the group of postflight reactions, i.e., a more marked reaction to LBNP. Thus, the available material enabled us to quantitatively assess the link between inflight MV changes, orthostatic stability and reactions to LBNP after the flight. The correlation between  $\Delta MV$  with IIOR and LDF of LBNP was determined separately for the first (1st-3d day) and second (4th-7th day) postflight tests.

## Results and Discussion

All inflight values for MV were lower than the mean preflight levels in 8 cosmonauts, they exceeded the mean but did not exceed the preflight range in 2 cases, they exceeded the top preflight level in 4. Depending on the nature of changes in inflight MV, all of the postflight results were divided into 2 groups: the first included data referable to 10 cosmonauts, in whom MV was low or remained in the preflight range, and the second--4 cosmonauts with MV exceeding the top of the preflight range.

Mean IIOR was higher in the first group of cosmonauts ( $73.16 \pm 2.17$ ) than in the second group ( $55.63 \pm 8.69$ ). The difference between means reached a statistically significant level ( $P < 0.05$ ). The mean LBNP LDF was lower with statistical significance in the first group than the second ( $19.36 \pm 0.44$  and  $21.44 \pm 0.63$ , respectively;  $P < 0.05$ ). Thus, the increase in MV during the flight beyond the top of the preflight range corresponded to relatively low orthostatic stability and relatively stronger reaction to LBNP.

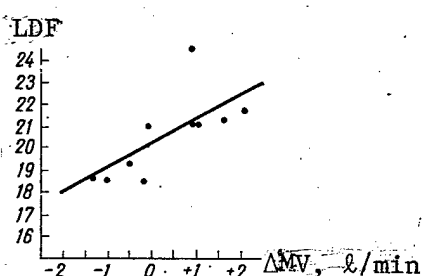
A more detailed analysis of the link between inflight MV changes and results of postflight functional tests was made by calculation of coefficients of paired correlation. The link between  $\Delta MV$  and IIOR in the first postflight orthostatic test was expressed by a statistically significant coefficient of correlation ( $r = -0.6$ ;  $P < 0.05$ ). The coefficient of correlation between MV and IIOR in the second postflight test had the same sign, but was somewhat lower and did not reach a statistically significant level ( $r = -0.52$ ). The means for IIOR for the two tests demonstrated a substantial correlation with  $\Delta MV$  ( $r = -0.59$ ). The results of the two postflight tests were closely correlated with one another ( $r = 0.84$ ). Analysis of the graph of IIOR as a function of  $\Delta MV$  revealed that a significant correlation exists between them only over a broad range of variation of  $\Delta MV$ . In the range of negative and

mildly positive  $\Delta MV$ , there was no correlation, and it appeared only when  $\Delta MV$  exceeded 1 l/min.

The link between  $\Delta MV$  and LDF in the first postflight LBNP test was characterized by a significant coefficient of correlation ( $r = 0.7$ ;  $P < 0.05$ ). LDF of LBNP as a function of  $\Delta MV$  could be described by a regression equation:

$$LDF \text{ LBNP} = 1.12 \Delta MV + 20.25$$

This function is illustrated in graphic form in the Figure. The coefficient of correlation between  $\Delta MV$  and LDF characterizing the second LBNP test retained a positive sign, but was very low. Unlike the first and second orthostatic tests, the results of the first and second LBNP tests failed to demonstrate a substantial correlation ( $r = 0.28$ ).



Postflight reaction to LBNP test as a function of inflight MV changes

X-axis, difference between mean preflight and inflight MV;  
y-axis, linear discriminant function characterizing reaction to LBNP

The positive correlation between  $\Delta MV$  and LBNP and negative correlation with LDF LBNP are indicative of a qualitatively identical nature of link between the two different functional tests and changes in inflight MV. The increase in MV corresponded to more marked decline of orthostatic stability and stronger reaction to postflight LBNP. Conversely, with low MV, as compared to preflight levels, we could expect relatively less decline of orthostatic stability and less accentuation of response to postflight LBNP. The cited coefficients of correlation were obtained on small samples of cases. Their maximum values satisfy only the lowest level of statistical significance adopted in biological studies [8]. However, the small size of the samples was compensated,

to some extent, by the use of two different functional tests which elicit redistribution of blood to the lower parts of the body and are mutually supplementary with regard to prognosis. The identical link between two different functional tests and the inflight MV changes indicates that such a link does indeed exist.

The inflight decline of MV is consistent with conceptions of diminished energy requirements of the body in weightlessness [9, 10]. The causes and mechanisms of inflight elevation of MV are not clear. MV was related quite closely to actual level of basal metabolism ( $r = 0.83$ ). However, in ground-based studies, where the effect on man of long-term weightlessness was simulated, demonstrated inconsistency between MV dynamics and energy expenditure [9]. Perhaps, the instances of increase in MV in flight and in the laboratory studies dealing with simulation of effects of weightlessness are analogous. From the practical point of view, it should be noted that the demonstrated correlations, if they are corroborated in future studies, disclose a basically new avenue for predicting orthostatic stability of cosmonauts after they return to earth on the basis of MV dynamics.

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HEMODYNAMIC REACTIONS TO POSITIVE INTRATHORACIC PRESSURE AT  $+G_z$  ACCELERATIONS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 21 May 82) pp 27-30

[Article by M. A. Tikhonov, D. Yu. Arkhangel'skiy, A. V. Kondakov and V. V. Litovchenko]

[English abstract from source] Eight male test subjects, aged 20-28, were exposed to acceleration  $+G_z$  and positive breathing pressure (PBP) of 30 mm Hg to study their hemodynamics under these conditions. The calculated and experimental decrease of blood pressure at the eye level during increasing acceleration and voluntary myorelaxation was comparable. The exposure to PBP helped tolerate higher (by  $1.1 \pm 0.2$  G) acceleration values without visual disorders. The exposure to 7.0 G and PBP caused a lower increase in heart rate and breathing frequency (by 6% and 12%, respectively), a smaller reduction of blood pressure at the eye level (by 20%) and a decreased muscular tension (by 18%).

[Text] Thanks to the extensive use of the method of breathing under excess [positive] pressure (PP) in aviation and clinical medical practice, the general patterns of physiological reactions to intrathoracic PP have been studied rather comprehensively [1-3]. However, these reactions differ appreciably, depending on magnitude, structure and means of creating PP, presence or absence of compensatory counterpressure, as well as concomitant exogenous factors. Our objective here was to investigate the distinctions of cardiovascular reactions when breathing under PP during exposure to  $+G_z$  accelerations.

#### Methods

Two series of tests on a centrifuge were conducted on 8 healthy males 20-28 years of age. In the first series, there was continuous buildup of accelerations with a gradient of 0.1 G/s to the limit of the subject's endurance with voluntary muscular relaxation; in the second series, there were accelerations with a gradient of 1.0 U/s and a "plateau" at 7.0 G for 30 s, with ordinary muscle tension.

Impairment of peripheral and central vision, group extrasystoles, severe general fatigue and marked respiratory difficulties were criteria for stopping exposure to accelerations.

In both series, the subjects wore anti-G suits and were exposed to each factor twice: while breathing under normobaric ambient air conditions and pure oxygen at PP of 30 mm Hg (4.0 kPa) using oxygen gear and mask.

We assessed the subjects' physiological reactions by recording the electrocardiogram (EKG) in the Neba leads, tetrapolar rheocardiogram, arterial pressure (BP) in vessels of the ear lobe, pneumotachogram, electromyogram (EMG) of intercostal muscles, thigh and abdomen, leg pressure on dynamometric pedals, simple sensorimotor reaction time to photic stimulus. We calculated the stroke (according to Kubichek) and minute volume [cardiac output] (SV, MV).

## Results and Discussion

All of the subjects reported that they endured accelerations better when breathing under PP, since this alleviated inspiration, required less tension of leg and abdominal muscles to retain clear vision. It was also significant that the objective evaluation of functional tension of the cardiovascular system according to several parameters conformed with the objective reports of the subjects.

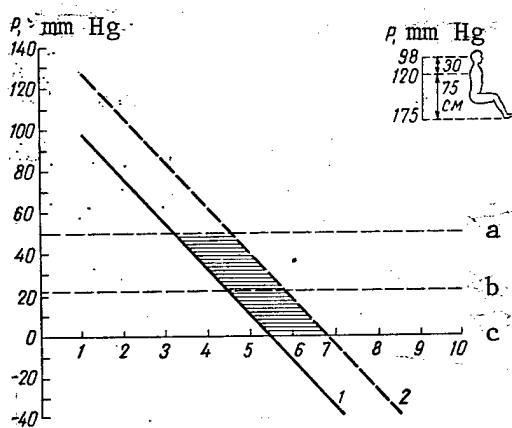


Figure 1.

Estimated dynamics of BP at eye level with exposure to +Gz accelerations when breathing normally (1) and at PP of 30 mm Hg (2)

- a) loss of peripheral vision
- b) loss of central vision
- c) loss of consciousness

First series. Determination of maximum acceleration was made with slow gradient of buildup and voluntary muscle relaxation, which provided for the time required to develop reflex compensatory reactions, while absence of muscular tension leveled off individual differences in resistance to accelerations due to experience and skill in effecting special antigravity contraction movements. For this reason, the limit of accelerations reached in a state of muscle relaxation characterizes primarily resistance of the cardiovascular system to accelerations, in particular its capacity to create adequate blood supply to the brain and retina at high gravity, since visual disturbances usually serve as criteria of maximum accelerations with relaxed muscles.

Behavior of a simple hemodynamic model (Figure 1) can serve as a working hypothesis for interpretation of the distinctions of cerebral circulation during exposure to accelerations.

According to anthropometric and hemodynamic assumptions made in this model, when the distance between the level of the heart and eye level is 30 cm [4], hydrostatic

pressure of such a column of blood constitutes 22 mm Hg, and while systolic BP at heart level at 1 G is 120 mm Hg, at eye level it is 98 mm Hg. In the case of strictly longitudinal accelerations, this pressure should drop by 22 mm Hg for every G of increase in acceleration.

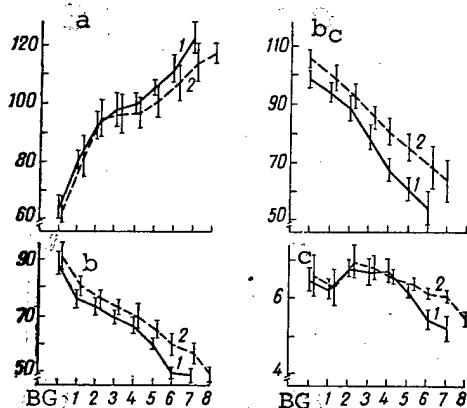


Figure 2.

Changes in some hemodynamic parameters as a function of magnitude of continuously growing accelerations during voluntary relaxation of muscles and breathing under ordinary conditions (1) and at PP (2)

- a) heart rate (per min)
- b) SV (ml)
- c) BP (mm Hg)      BG) background
- d) MV (l/min)

model cannot reflect the corrective influence of hemodynamic reflexogenic reactions and muscle tension, so that it can only be used for preliminary estimates.

Nevertheless, the results of the studies demonstrate that they compare well with estimated data. For example, under actual conditions, when breathing at PP of 30 mm Hg, visual disorders appeared at accelerations that were  $1.1 \pm 0.2$  G greater than the usual level at which they occurred, i.e., the actual elevation of this level was close to the estimate (1.25 G). The real dynamics of BP decline at eye level (in vessels of the ear lobe) that explain these findings were also close to the estimates (see Figures 1 and 2). The differences observed in parameters are apparently attributable to use of part of the PP energy to stretch elastic structures of the lungs and blood vessels.

The relative decline of heart rate (HR) and less intensive decrease in SV and MV (see Figure 2) also reflected some pattern in cardiovascular function when breathing at PP during slowly increasing accelerations.

The solid line in Figure 1, which reflects the hypothetical decline of pressure at eye level as a function of magnitude of accelerations, intersects several critical levels established empirically, which correspond to loss of peripheral, central vision and consciousness [5, 6]. The estimated points of intersection of the line of BP decline and critical levels coincides satisfactorily with actual data obtained with voluntary relaxation of muscles [7], thereby confirming the validity of the proposed model.

Intrathoracic PP created with voluntary tension of muscles (Valsalva type procedures) or automatically, by means of oxygen gear, is transmitted through the chambers of the heart, carotids and jugular veins to intracranial vessels; it raises BP at eye level and, consequently delays development of visual disorders. Thus, according to Figure 1, with intrathoracic PP of 30 mm Hg, the disturbances referable to peripheral and central vision should shift by 1.25 G in the case of direct (without losses) transmission of PP over the vascular system. Obviously, a simple mechanical



Thus, the method of voluntary muscle relaxation during exposure to accelerations can be viewed as an analytical procedure which permits isolation and evaluation of the compensatory capability of the cardiovascular system as the basis of the body's antigravity potential. Other components are superimposed over this foundation, and they determine integral resistance to accelerations: muscular tension, endogenous or exogenous elevation of intrathoracic pressure, effect of various anti-G apparatus, etc.

Effect of Head-pelvis accelerations of 7 G when breathing air under normobaric conditions and oxygen at PP of 30 mm Hg on functional tension of cardiovascular and muscular systems (M±m)

Parameter	Breathing conditions	Back-ground	7 G "plateau"			
			10 s	20 s	30 s	
HR, per min	Air, PP	O <sub>2</sub>	78±7	142±7	158±5	150±7
Respiration rate, per min	Air, PP	O <sub>2</sub>	80±8	138±7	148±6	144±6
			22±1	38±1	40±1	36±2
			22±1	36±2	35±1	34±3
Systolic BP in ear concha, mm Hg	Air, PP	O <sub>2</sub>	123±12		90±14	
Pressure on pedal, kg	Air, PP	O <sub>2</sub>	125±10		112±15	
			—	160±20	145±20	132±20
EMG of thigh, μV	Air, PP	O <sub>2</sub>	—	122±20	120±15	110±15
			—	500±24	340±37	380±64
EMG of oblique abdominal muscles, μV	Air, PP	O <sub>2</sub>	—	320±37	260±29	300±32
			—	280±42	300±28	330±36
			—	220±36	240±18	270±24

Second series. A study was made of hemodynamic responses with exposure to accelerations with rapid buildup gradient and ordinary muscular tension, i.e., under close to real conditions. In such conditions, we also observed better (with less muscular exertion and fatigue) endurance of submaximum accelerations of 7.0 G in the respiratory system of the subjects when using PP, which is confirmed by the following objective data (see Table): relatively less (by 6%) HR increment and less (by 12%) increment of respiratory rate (RR), less (by 20%) decline of systolic BP in ear lobe vessels, decline (by 25 and 17%) of EMG amplitude for muscles of the thigh and abdomen, decrease (18%) of leg pressure on pedals as an indicator of general muscular tension (comparative data for 10-20-s interval of the acceleration "plateau").

During exposure to accelerations when breathing under ordinary conditions, the EKG showed four cases of ventricular extrasystole, including two cases of multiple extrasystoles. When breathing under PP no multiple extrasystole was demonstrable and there were two cases of isolated extrasystoles.

Analysis of the causes of limited resistance to accelerations revealed that, when breathing at PP, we did not demonstrate the combination of complaints of severe physical fatigue with concurrent visual impairment and breathing difficulty, which is the most common under ordinary conditions. Discrete disturbances of cardiac rhythm or vision, which were not related in time, were the prevalent causes of discontinuing accelerations when breathing under PP.

On the whole, the results of this study confirm the validity of the hypothesis that excessive intrathoracic pressure during exposure to accelerations is not an exotic factor for the body: as a rule, pilots use special procedures of muscular tension during exposure to accelerations, an attempt being made to breathe out through the entirely or partially closed rima. In this case, intrathoracic pressure could rise significantly.

Thus, intrathoracic PP during exposure to longitudinal head-pelvis accelerations has several positive physiological effects that enhance man's resistance to accelerations.

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NORMAL HUMAN CORONARY CIRCULATION DURING POSTURAL TESTS AND DECOMPRESSION  
OF LOWER HALF OF BODY

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[Article by V. Ye. Katkov, V. V. Chestukhin, V. V. Rumyantsev, Ye. V.  
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[English abstract from source] The effect of postural changes (orthostatic and antiorthostatic tests) and LBNP on coronary circulation was investigated in 11 healthy male test subjects. Volume blood flow velocity and pressure were measured and blood flowing from the heart was withdrawn using a Ganz catheter implanted into the coronary sinus. A thin Teflon catheter was implanted into the brachial artery. When the test subjects were transferred from the recumbent to the head-up position their left ventricular oxygen consumption decreased by 3.2 ml/min (21%) and coronary blood flow by 23.8 ml/min (19%), while coronary vascular resistance increased by 32%. When the test subjects were transferred from the head-up to the head-down position (at  $-15^{\circ}$ ), coronary oxygen consumption and blood flow increased by 5.5 (46%) and 45.3 (44%) ml/min, respectively, and coronary resistance decreased by 36%. In this situation the LBNP test ( $-30$  mm Hg for 20 min) caused a reduction in oxygen consumption and coronary blood flow by 4.4 (25%) and 37.3 (25%) ml/min, respectively, and an increase in coronary resistance by 58%.

[Text] A change in blood supply to the myocardium during an orthostatic test or simulation of its effect--negative pressure to lower half of the body (LBNP)--could play an important role in adaptation of the heart and circulation as a whole to these factors. There are only a few works in the literature concerned with this matter, and the studies were pursued on animals [1-3]. One of the causes of this is the difficulty of recording volumetric rate of coronary blood flow in man. In particular, to estimate  $O_2$  uptake by the myocardium we must know the oxygen content in blood flowing to and from the heart, for which purpose the peripheral artery and coronary sinus must be catheterized.

Our objective here was to test the effect of postural factors and LBNP on coronary circulation and oxidative metabolism of the normal human myocardium (left ventricle).

## Methods

We had under observation 11 healthy men who had undergone a thorough medical work-up (average age 35 years, height 176 cm and weight 82 kg). One day before the postural and LBNP tests, under hospital conditions, we implanted special catheters in their coronary sinus and brachial artery.

Special Ganz catheters (model CCS-7U-90A or CCS-7U-90B) with thermistors (W. W. Labs, California) were introduced under x-ray monitoring (Siemens) through the left subclavian vein into the coronary sinus, and this enabled us to record simultaneously the volumetric flow rate in the coronary sinus and large cardiac vein, measure pressure in this region and take samples of blood flowing from the heart. The location of the catheter in the coronary sinus was verified by injection of contrast medium, determination of oxygenation ( $\text{HbO}_2$  and  $\text{pO}_2$ ) and recording retrograde blood flow in the region, as well as stability of blood temperature.

Volumetric blood flow rate in the coronary sinus was recorded by the method of continuous infusion of a thermoindicator (saline at room temperature). It was injected for 15-20 s in the coronary sinus at a constant rate (32 or 38 ml/min), using a pump manufactured by Sage Instruments, Orion Res. Inc. Mass (model 351). Volumetric flow rate was measured with a CF-300 (W. W. Labs, California) flowmeter; it was recorded with an Omni Scribe (Houston Inst.) automatic recorder. The biophysical bases of the technique, validation of its use, advantages and disadvantages are discussed by Ganz et al. [4]. Several more recent publications deal with the same questions [5-10].

Stable position of catheters (thermistors) in the coronary sinus is one of the most important factors affecting accuracy of measurements. In the case of postural and LBNP tests, when the position of the heart can change, this is a very difficult task. Blood flow over the entire coronary sinus was recorded, determining the region where it was stable, with the subject in the base (horizontal) position, in order to reduce measurement errors. The thermistor was in this area, but no closer than 1.5 cm from the exit of the coronary sinus. During postural and LBNP tests, the region of the coronary sinus was x-rayed in order to define the position of the thermistor. When necessary, the catheter was repositioned under x-ray monitoring. In addition, the catheter was attached rather securely to the chest at the site of insertion.

Arterial pressure and pressure in the coronary sinus were measured with model 746 (Siemens) electric manometers situated on the level of the right atrium, and they were recorded on a Mingograf-82 automatic recorder. Parameters of acid-base status and blood oxygenation were determined using an AVL-940 automatic gas analyzer and hemoglobin was measured with the Hemolux instrument.

One day after implanting the catheters, the subjects were placed on an orthostatic table in horizontal position. They were moved to vertical

position (60°, 15 min) 15-20 min after recording all parameters. The table was then moved to antiorthostatic position (-15°, 20 min) and lower body decompression [LBNP] was created (-30 mm Hg).

We calculated myocardial (left ventricular)  $O_2$  uptake as the product of multiplying volumetric blood flow rate in the coronary sinus by arteriovenous difference for oxygen; resistance of coronary vessels was calculated as the ratio of perfusion pressure (mean arterial pressure minus pressure in coronary sinus) to blood flow.

The results were submitted to mathematical processing; we used Student's  $t$  criterion, the criterion of Z signs and coefficients of correlation of parameters for statistical analysis.

### Results and Discussion

Figure 1 illustrates a tracing of volumetric blood flow rate in the coronary sinus (pulsed and mean) recorded in one of the subjects (K-s) in horizontal position. This parameter was subject to significant individual variations, and it ranged from 61 to 180 ml/min (average for the group  $125.8 \pm 11.0$  ml/min). Individual fluctuations of oxygenation were not as marked; for example, arteriovenous difference for  $O_2$  of the heart was in the range of 10.9-13.6 vol.% (average  $12.2 \pm 0.3$  vol.%) (Table 1).

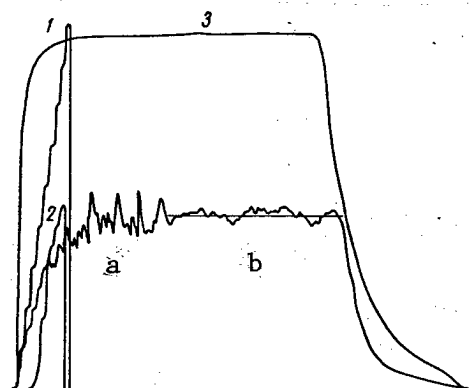


Figure 1.

Original tracing of volumetric blood flow rate in coronary sinus recorded on one of subjects

- 1) calibration signal of external thermistor
- 2) calibration signal of internal thermistor (each gradation of both signals 100  $\Omega$ )
- 3) temperature indicator (measured by internal thermistor)
- a) pulsed blood flow
- b) mean blood flow, 123 ml/min

higher than in horizontal position and considerably higher than in orthostatic position (see Table 1). LBNP elicited about the same change in this

The change to orthostatic position was associated with reliable decrease in coronary sinus blood flow. Myocardial  $O_2$  uptake in such cases also diminished, whereas resistance of coronary vessels increased. This was observed against a background of pressure drop in the coronary sinus and increase in heart rate; mean arterial pressure remaining unchanged, perfusion pressure demonstrated a tendency toward elevation. This was associated with decline of  $pCO_2$  and elevation of  $pO_2$  of arterial blood;  $pCO_2$  dropped also in coronary sinus blood (Table 2).

In orthostatic position 2 of the subjects showed increase in coronary sinus blood flow: by 37 ml/min (25%) in one case (F-ov), which was combined with elevation of perfusion pressure by 20.5 mm Hg, and in the other subject (K-ov) in the presence of tachycardia (100/min) by 13 ml/min (12%).

In head-down position, blood flow and pressure in the coronary sinus were

parameter, as well as in  $O_2$  uptake by the myocardium and resistance of coronary vessels as the orthostatic test, whereas heart rate did not change appreciably. At the same time, the change in gas content of arterial blood was less marked, and there was no decline of  $pCO_2$  of coronary sinus blood.

Table 1. Parameters of normal coronary circulation during postural tests and LBNP

Parameter		Horiz. position	Orthost. test (60°)	Anti- orthost. test (-15°)	LBNP (-30° mm Hg)	$P_{1-2}$	$P_{2-3}$	$P_{3-4}$
CSF, ml/min	$M \pm m$	125,8 $\pm$ 11,0	102,0 $\pm$ 10,7	147,3 $\pm$ 15,8	110,0 $\pm$ 16,7	<0,05	<0,05	<0,01
	$n$	10	10	10	10			
	max.	180	155	223	182			
	min.	61	45	65	24			
ABPO <sub>2</sub> , vol. %	$M \pm m$	12,2 $\pm$ 0,3	11,9 $\pm$ 0,26	12,0 $\pm$ 0,34	11,9 $\pm$ 0,28	<0,05	>0,05	>0,05
	$n$	10	10	10	10			
	max.	13,6	12,7	13,4	12,9			
	min.	10,9	9,9	10,2	10,3			
MVO <sub>2</sub> , ml/min	$M \pm m$	15,2 $\pm$ 1,20	12,0 $\pm$ 1,2	17,5 $\pm$ 1,8	13,1 $\pm$ 2,1	<0,05	<0,01	<0,05
	$n$	10	10	10	10			
	max.	20,6	18,3	25,0	23,9			
	min.	8,2	5,7	8,3	3,0			
CVR, units	$M \pm m$	0,73 $\pm$ 0,1	0,96 $\pm$ 0,2	0,62 $\pm$ 0,1	1,07 $\pm$ 0,3	<0,05	<0,01	<0,01
	$n$	8	8	11	11			
	max.	1,50	2,30	1,39	3,83			
	min.	0,47	0,56	0,35	0,45			
PP	$M \pm m$	84,9 $\pm$ 3,3	91,0 $\pm$ 2,9	83,9 $\pm$ 2,0	88,3 $\pm$ 2,4	>0,05	<0,05	>0,05
	$n$	8	8	11	11			
	max.	97	105	92,5	96			
	min.	73	81	72	68,5			
SBP, mm Hg	$M \pm m$	121,8 $\pm$ 3,8	118,8 $\pm$ 3,0	121,5 $\pm$ 2,3	114,6 $\pm$ 2,1	>0,05	>0,05	>0,05
	$n$	8	8	11	11			
	max.	140	130	135	125			
	min.	110	110	105	100			
HR/min	$M \pm m$	69,7 $\pm$ 2,9	81,3 $\pm$ 3,9	68,9 $\pm$ 3,3	74,4 $\pm$ 3,9	<0,01	<0,01	>0,05
	$n$	10	10	11	11			
	max.	88	100	88	96			
	min.	60	68	56	56			
CSP	$M \pm m$	2,4 $\pm$ 0,9	-0,7 $\pm$ 0,6	4,2 $\pm$ 1,2	-0,4 $\pm$ 0,9	<0,01	<0,05	<0,01
	$n$	10	10	11	11			
	max.	5	2	12,5	5,0			
	min.	0	-3	-1,0	-4,0			

Key (for this and Table 3):

- CSF) blood flow in coronary sinus
- ABPO<sub>2</sub>) arteriovenous difference for oxygen
- MVO<sub>2</sub>) oxygen uptake by left ventricle of the heart
- CVR) coronary vessel resistance
- PP) perfusion pressure
- SBP) systolic arterial pressure
- HR) heart rate
- CSP) coronary sinus pressure

We were impressed by the fact that, in spite of the significant changes in coronary sinus blood flow during postural tests and LBNP, it was always in close linear relation to  $O_2$  uptake by the left ventricle (Figure 2). Correlation analysis revealed that there was also a close link between blood

flow and resistance of coronary vessels, whereas the coefficient of correlation with other parameters was not as high (Table 3).

Table 2. Parameters of acid-base balance and oxygenation of arterial (A) blood and blood from the coronary sinus (CS) during postural tests and LBNP

Parameter studied	Horizontal position		Orthostatic test (60°)		Antiorthostat. test (15°)		LBNP (-30 mm Hg)	
	A	CS	A	CS	A	CS	A	CS
pH	7.41 ± 0.007	7.360 ± 0.01	7.432 ± 0.006	7.383 ± 0.007	7.426 ± 0.01	7.374 ± 0.007	7.422 ± 0.009	7.381 ± 0.009
pCO <sub>2</sub> , mm Hg	36.6 ± 0.6	46.1 ± 1.2	34.8 ± 0.3*	40.9 ± 1.4*	35.5 ± 0.6	42.7 ± 1.2	34.2 ± 0.6	42.4 ± 1.5
BE, mmol/l	-8.8 ± 0.46	-0.5 ± 0.83	-0.5 ± 0.41	-1.1 ± 0.62	-0.6 ± 0.66	-0.9 ± 0.57	-1.4 ± 0.65	-0.5 ± 0.82
pO <sub>2</sub> , mm Hg	85.9 ± 3.7	21.4 ± 0.7	94 ± 3.5	21.5 ± 0.5	87.1 ± 2.9	21.6 ± 0.6	80.4 ± 3.5	21.4 ± 0.6
HbO <sub>2</sub> , %	96.3 ± 0.5	31.7 ± 1.6	97.4 ± 0.3	34.4 ± 1.3	96.7 ± 0.3	34.2 ± 1.5	96.9 ± 0.3	34.0 ± 1.3

\*Reliability of difference P<0.05.

Table 3. Coefficients of correlation between blood flow in coronary sinus and parameters of circulation and oxidative metabolism

Test conditions	CSP	PP	CVR	HR	SBP	MVO <sub>2</sub>	ABPO <sub>2</sub>
Horizontal position	-0.68*	-0.27	-0.91**	0.55	-0.29	0.965**	-0.60
n	10	8	8	10	8	10	10
Orthostatic test	0.16	-0.45	-0.90**	0.39	-0.31	0.971**	-0.47
n	10	8	8	10	8	10	10
Antiorthostatic posit.	0.23	-0.16	-0.90**	0.30	-0.21	0.949**	-0.29
n	11	11	11	11	11	10	10
LBNP (-30 mm Hg)	0.47	-0.03	-0.80**	0.37	0.12	0.985**	-0.09
n	11	11	11	11	11	10	10

\*Reliability of difference P<0.05.

\*\*Reliability of difference P<0.01.

A comparison of dynamics of myocardial O<sub>2</sub> uptake, as determined from direct measurement (product of coronary blood flow multiplied by arteriovenous difference for O<sub>2</sub>) and indirect evaluation (product of systolic blood pressure multiplied by heart rate) is illustrated in Figure 3. As can be seen in this figure, the dynamics of this parameter were largely related to the method by which it was measured during the tests used.

Blood flowing in over coronary arteries can be diverted from the heart over different routes, but the principal ones are the coronary sinus, atrial and ventricular Vieussens' and thebesian veins and veins of the transitional pericardial fold. In particular, blood from the left ventricle flowing in from the left circumflex and anterior descending arteries is removed mainly through the coronary sinus [11-15]. As shown by Hood [14], in man 96% of all veins over 1 mm in diameter remove blood from the anterior wall

of the left ventricle and septum to the coronary sinus, and only 17% of the veins going into the coronary sinus drain blood out of other regions. Thus, the blood flow we measured in the coronary sinus reflects primarily overall perfusion of the left ventricle, which differs in different people.

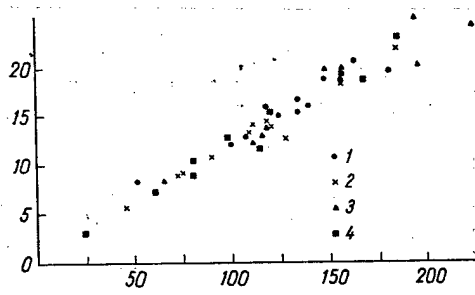


Figure 2.

Correlation between overall blood flow in left ventricle of the heart and its  $O_2$  uptake during postural tests and LBNP.

X-axis, total blood flow in left ventricle (ml/min); y-axis, oxygen uptake by left ventricle (ml/min)

Dots: horizontal position  
Crosses: orthostatic position  
Triangles: antiorthostatic position  
Squares: LBNP

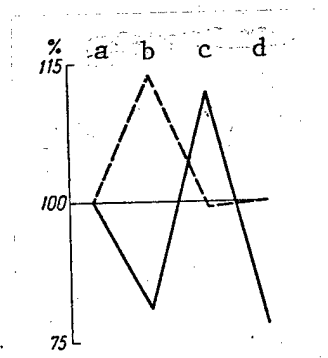


Figure 3.

Actual (solid line) and estimated (dash line)  $O_2$  uptake (%) by heart during postural tests and LBNP

a) horizontal position  
b) orthostatic position  
c) antiorthostatic position  
d) LBNP

In horizontal position, blood flow constituted a mean of  $125.8 \pm 11.0$  ml/min, with individual fluctuations from 61 to 180 ml/min. Approximately the same results were obtained by the method of Ganz et al. [4] on patients with normal coronary arteries. In 14 people, average blood flow in the coronary sinus constituted  $122 \pm 25$  ml/min and ranged from 83 to 159 ml/min. As noted by the authors, these figures are close to those recorded in other studies using the methods of flushing radioactive isotopes and Kety-Schmidt.

Since the mass of the human left ventricle is an average of about 150 g, one can scale blood flow and  $O_2$  uptake per 100 g tissue. In our subjects, it would be 83.9 and 10.1 ml/min/100 g, respectively, which corresponds well to data in the literature [6, 7].

Use of the proposed method with functional gravity tests may be difficult due to change in position of the catheter (thermistor) and because of possible ejection of blood via parasinus efflux pathways (mainly over Vieussens' and thebesian veins). With regard to the role of parasinus efflux routes (and shunting of blood in the myocardium) there has been a debate in the literature for a long time. We should mention one important factor that is inherent in gravity tests. Under such conditions, average pressure in both atria, as well as end diastolic pressure in the ventricles, change in the same way. This means that one of the principal causes of involvement of



parasinus efflux pathways is not present in this situation. For expressly this reason, not only did blood flow fail to diminish in the coronary sinus against the background of drastically elevated pressure in it in antiorthostatic position, on the contrary, it increased in accordance with the requirements of the myocardium. It should be noted that, throughout the study, coronary blood flow was adequate to the metabolic demands of the left ventricle, since several parameters of acid-base balance in blood flowing from it (primarily base excess) remained relatively stable in the presence of a constant coefficient of  $O_2$  extraction.

Our results indicate that gravity factors have an appreciable influence on myocardial  $O_2$  uptake, blood flow in the coronary sinus and resistance of coronary vessels. This conforms to data in the literature, which were obtained in experiments with animals. In particular, Langou et al. [3] showed that, during the orthostatic test ( $30^\circ$ ), when systolic pressure in the left ventricle, parameters of contractility and heart rate did not change appreciably, coronary blood flow ( $^{133}\text{Xe}$ ) and myocardial  $O_2$  uptake in dogs diminished from 149 to 118.2 (21%) and from 17.4 to 11.8 (32%) mg/min/100 g, respectively. The authors arrived at the conclusion that the orthostatic test can be used to treat patients with ischemic heart disease. Nutter et al. [1], who studied the effect of LBNP on central circulation, advanced the hypothesis that it could reduce appreciably myocardial  $O_2$  uptake and coronary blood flow.

Oxygen taken up by the myocardium is used for its basal metabolism, contraction and external function (Fenn effect) [13, 16-20]. The level of  $O_2$  uptake depends on a number of hemodynamic factors: tension of the left ventricular wall, systolic and end diastolic pressure, volume of contractile state, heart rate and other factors [18-24]. During the orthostatic test and LBNP, complex correlations are observed between these factors, when increase in some (heart rate) is instrumental in increased  $O_2$  uptake by the myocardium, whereas decrease in others (tension of left ventricle wall, end diastolic pressure and volume, stroke and minute volumes, external function) leads to a decline [25, 26]. The contractile state of the left ventricle of the heart ( $\max dp/dt$ ,  $\max dp/dt/P$ ,  $V_{\max}$ ) showed virtually no change with these factors, and apparently it has little influence on the parameters studied [26]. Since the increase in heart rate during these tests is usually insignificant and constitutes 5-15%, while parameters of the second group drop by 17-80%, the overall effect, which was not related to change in blood gas content, was a decrease in myocardial  $O_2$  uptake and coronary blood flow.

This complex interaction was probably the chief cause of inconsistency between estimated and experimental  $O_2$  uptake by the myocardium. A high correlation does not exist always by far between estimated and experimental levels of this uptake [27]. As for gravity factors, the estimated values should be used with great caution.

The change from orthostatic to antiorthostatic position can be used to simulate the "acute" period of adaptation to weightlessness. Under these conditions, a drastic elevation of end diastolic pressure and increase in volume of the left ventricle are observed, as well as tension that it

develops, which, as we have noted above, are important determinants of  $O_2$  uptake by the myocardium and coronary blood flow [18, 24, 26]. Since perfusion pressure drops in this case, the increase in coronary blood flow occurs due to decrease in resistance of coronary vessels. If the same situation is observed in weightlessness, it can be assumed that it leads to reduction of the myocardial coronary reserve, which is used in part to assure adequate blood supply to it. Apparently, it can be considered that these conditions are not physiological for the myocardium, and that correction is required to normalize them. Use of LBNP in such cases improves the situation; however, additional studies are needed to find the optimum conditions for using this factor.

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DYNAMICS OF RHEOGRAPHIC PARAMETERS OF CEREBRAL CIRCULATION AND CIRCULATION  
IN THE EXTREMITIES DURING ACTIVE ORTHOSTATIC TEST

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17,  
No 5, Sep-Oct 83 (manuscript received 5 Oct 82) pp 36-39

[Article by N. I. Sapova]

[English abstract from source] Rheography was used to study brain, leg and forearm circulation in 30 male test subjects during tilt tests. In the head-up position blood circulation in the above body parts decreased due to a reduction of stroke volume. The orthostatis reaction was considered normal, provided that leg blood content decreased and tone increased, cerebral and forearm blood content and tone varied slightly, and rheographic parameters in the stationary states (lying and standing) remained unchanged.

[Text] A number of complex functional changes take place in the human body that are aimed at maintaining homeostasis in upright position when man changes actively from horizontal to erect position [1-5]. Researchers, who used rheography to study circulation during orthostatic tests obtained rather contradictory data concerning the dynamics of filling and tonus of vessels of the brain and extremities, apparently because they considered different sets of rheographic parameters, recorded rheograms at different times after changing body position, and they analyzed a dissimilar number of rheographic waves [6, 7, 8]. Yet routine dynamic monitoring of changes in orthostatic stability of individuals in certain occupations, including pilots [9], makes it necessary to define rheographic criteria characterizing the optimum response to an orthostatic factor. An effort was made here to determine the distinctions of changes in cerebral and extremital circulation of healthy subjects during an active orthostatic test by means of rheography.

Methods

A total of 30 essentially healthy men, 20-35 years of age, who did not engage in sports participated in this study. According to the results of questioning them, all were right-handed. They were submitted to the active orthostatic test under comfortable microclimate conditions, with recording of rheoencephalograms in the left and right frontomastoid leads (REG<sub>l</sub> and REG<sub>r</sub>), rheovasograms of the right lower leg (RVG<sub>c</sub>) and right forearm

(RVG<sub>fa</sub>), integral rheograms of the body (IRG), intervalocardiograms (IKG) and arterial pressure (BP) by the auscultative method. We used a 4RG-1 rheographic attachment to record the rheograms and a Periodometer to record intervalocardiograms.

We analyzed only the REG and RVG parameters that, in our opinion, were the most informative (changed the most and the soonest with different loads and under the effect of adverse ambient factors, showed little correlation with one another under ordinary living conditions): parameters of pulsed influx (RI--rheographic index) and minute influx of blood (MI-RI×PR [pulse rate], coefficient of tonic tension (CTT -  $\alpha/T$ ), dicrotic and diastolic indexes (DCI, DSI), coefficient of asymmetry ( $CA = RI_{REG1}/RI_{REGr}$ ). Stroke volume of the heart was determined by calculation [10] from the IRG parameters. The IKG was recorded continuously on all subjects throughout the test period. REG, RVG, IRG were also recorded continuously on 9 subjects and discretely in the others, since the first stage of the investigation revealed that the optimum epoch for analysis is referable to 20 successive rheographic cycles (waves), because with this epoch of analysis there is leveling off of respiratory and slow (10-20-s period) oscillations of rheographic parameters [11]. These 20 cycles were recorded after spending 3-5 min in supine position and 1.5-2 min after moving to erect position. The stationary level of cardiac cycles was determined from the IKG. We also analyzed variability of parameters in each subject (coefficient of variation over the chosen epoch of analysis--20 cycles).

When comparing data obtained for subjects in the same group, we used the method of Student; for related data, and the method of Wilcoxon; when comparing data referable to different groups we used the method of Student for unrelated data and the method of Wilcoxon-Mann-Whitney. We also performed statistical processing with use of regression and single-factor variance analysis.

## Results and Discussion

The duration of the cardiac cycles diminished on the average from  $957 \pm 23$  to  $769 \pm 22$  ms with change from horizontal to erect position; stroke and minute volumes changed from  $73 \pm 4$  to  $45 \pm 3$  ml and from  $4.74 \pm 0.16$  to  $3.98 \pm 0.21$  l/min, respectively ( $P < 0.01-0.001$ ). BP was virtually the same in supine and erect positions. Regression analysis failed to demonstrate any significant link between rheographic parameters and duration of cardiac cycles, stroke or minute volume and BP in either erect or recumbent positions.

Right after changing position, RI for vessels of the parts of the body studied first rose by 10-30% then, 20-50 s later, a new quasistationary level was established for this parameter. Analogous data on changes in influx of blood to cerebral vessels were obtained by other investigative methods [12]. The parameters of vascular tonus underwent appreciable fluctuations of different amplitude and period in this transitional period, unlike the orderly oscillations in stationary states (in supine and erect positions), and the spread of these fluctuations was wider than at the stationary level.

Dynamics of REG and RVG of extremities during active orthostatic test ( $\bar{x} \pm S_{\bar{x}}$ ,  $n = 30$ )

Parameter	Rheoencephalography, frontomastoid lead				Rheovasography of extremities			
	left hemisphere		right hemisphere		right lower leg		right forearm	
	supine	erect	supine	erect	supine	erect	supine	erect
RI, $\Omega$	0.138 $\pm$ 0.008	0.116 $\pm$ 0.008*	0.143 $\pm$ 0.009	0.117 $\pm$ 0.010*	0.051 $\pm$ 0.004	0.035 $\pm$ 0.002***	0.080 $\pm$ 0.006	0.064 $\pm$ 0.005**
MI, $\Omega/\text{min}$	8.64 $\pm$ 0.53	9.14 $\pm$ 0.69	8.39 $\pm$ 0.77	9.23 $\pm$ 0.64	3.21 $\pm$ 0.24	2.77 $\pm$ 0.18**	4.97 $\pm$ 0.35	5.20 $\pm$ 0.51
CTT	0.166 $\pm$ 0.007	0.177 $\pm$ 0.017*	0.164 $\pm$ 0.007	0.179 $\pm$ 0.008*	0.150 $\pm$ 0.005	0.157 $\pm$ 0.008*	0.132 $\pm$ 0.008	0.156 $\pm$ 0.008*
DCI	0.759 $\pm$ 0.022	0.787 $\pm$ 0.017	0.750 $\pm$ 0.021	0.742 $\pm$ 0.023	0.366 $\pm$ 0.030	0.531 $\pm$ 0.026***	0.500 $\pm$ 0.037	0.481 $\pm$ 0.031
DSI	0.832 $\pm$ 0.028	0.826 $\pm$ 0.017	0.811 $\pm$ 0.027	0.865 $\pm$ 0.017	0.422 $\pm$ 0.030	0.622 $\pm$ 0.028***	0.636 $\pm$ 0.033	0.647 $\pm$ 0.030

\*Reliability 95%

\*\*99%

\*\*\*99.9%

(Reliability is indicated regardless of whether it was proven by a parametric or nonparametric method.)

In erect position, RI dropped to the same extent in both cerebral hemispheres--by 13-16%, CTT increased insignificantly, while MI, DCI and DSI did not undergo reliable changes (see Table).

Reliable regression equations were obtained, which demonstrated the relationship between RI (in  $\Omega$ ) and MI (in  $\Omega/\text{min}$ ) in erect [subscript e] and supine [s] positions.

$$\text{REG}_1: \begin{aligned} \text{RI}_e &= 0.034 + 0.76 \text{RI}_s - 0.8 \text{RI}_s^2 \\ \text{MI}_e &= 3.88 + 0.54 \text{MI}_s - 0.01 \text{MI}_s^2 \end{aligned}$$

$$\text{REG}_r: \begin{aligned} \text{RI}_e &= 0.019 + 1.04 \text{RI}_s - 2.1 \text{RI}_s^2 \\ \text{MI}_e &= 1.01 + 1.33 \text{MI}_s - 0.05 \text{MI}_s^2 \end{aligned}$$

No dependence of individual values for these parameters with subjects in erect position on their values in supine position was demonstrable in the range of values of CTT, DCI and DSI of the REG and RVG inherent in healthy people; this also applied to a link between vascular tonus and influx of blood to vessels.

The coefficient of asymmetry constituted 1.05 $\pm$ 0.07 in supine position and 1.07 $\pm$ 0.09 in upright position. There were rather significant differences between individual CA. Relatively symmetrical filling of cerebral vessels (CA = 0.95-1.05) was noted in 7 subjects (23%), right-sided asymmetry in 10 (33%) and left-sided in 13 (44%). Filling of the dominant (with regard to influx of blood) hemisphere was 20-30% greater than of the subdominant. RI in the dominant (left and right respectively) hemisphere constituted 0.148 $\pm$ 0.014 and 0.158 $\pm$ 0.015  $\Omega$ , respectively, in supine position, 0.118 $\pm$ 0.011 and 0.128 $\pm$ 0.007  $\Omega$  in erect position; in the subdominant hemisphere the figures were 0.117 $\pm$ 0.014 and 0.121 $\pm$ 0.013  $\Omega$  in horizontal position, 0.110 $\pm$ 0.014 and 0.092 $\pm$ 0.007  $\Omega$  in erect position. When

standing, CTT increased reliably by 6-10% ( $P < 0.05$ ) only in the dominant hemisphere. The lower DCI on the REG<sub>1</sub> of subjects with symmetry and left-sided asymmetry of filling was attributable to the factor of asymmetry of filling (influence of factor 14.8%;  $P = 0.05$ ). Individual distinctions of filling of the dominant (according to blood influx) hemisphere persisted to a greater extent in the orthostatic test than those of the subdominant hemisphere ( $r = +0.607$  to  $+0.674$ ,  $P < 0.05$ , and  $r = +0.256$  to  $+0.417$ ,  $P > 0.05$ ).

It was noted that DCI and DSI of the RVG<sub>c</sub> was 13-25% lower, while DCI RVG<sub>fa</sub> was 23-24% lower in subjects with symmetry and left-sided asymmetry of brain filling in erect position than in subjects with right-sided asymmetry (degree of influence of asymmetry factor 14.5-23%,  $P < 0.05$ , and 10.8-13.2%,  $P < 0.1$ , respectively).

On the whole, RI decreased by 31% in erect position for crural vessels and 20% for vessels of the forearm (see Table). During the orthostatic test, MI of forearm vessels did not change, while it diminished for crural vessels. There was rather insignificant increase in CTT on RVG<sub>c</sub> and RVG<sub>fa</sub> in erect position, while DCI and DSI of RVG<sub>c</sub> was 1.3-1.5 times higher in all subjects than in horizontal position, which is indicative of substantial increase in tonus of small-caliber vessels.

The variability of REG and RVG parameters with change in body position was stable: the coefficient of variation of these parameters held at the level of 9-16% (i.e., the fluctuations of rheographic parameters in 10-20 s constituted  $\pm 20$ -35% of their average values).

Thus, the common reaction to orthostatic factors was a decline of RI: in 76% of the cases for cerebral vessels, 87% for vessels of the forearm and 100% for crural vessels. This changes were probably related to decline of stroke volume, which is considered an adequate response in erect position [2]. Nevertheless, in spite of the decrease in minute volume during the orthostatic test, MI did not decrease in cerebral and forearm vessels, due to maintenance of optimum blood supply to these parts of the body. At the same time, the substantial decrease in filling and increase in tonus of crural vessels reflect a very valid reaction aimed at compensation of the adverse hemodynamic changes arising in upright position, which are instrumental in preserving venous return to the heart [1, 3]. In this case, the principal factor is constriction of small vessels, which prevents hemostasis in the lower limbs in upright position. Consequently, a mandatory decline of RI, increase of DCI and DSI on the RVG<sub>c</sub> and insignificant change in parameters characterizing tonus of cerebral and forearm vessels, with some decline of blood RI in these vessels, are unconditional criteria of a normal orthostatic reaction. The relative stability of variability of rheographic parameters, particularly RVG<sub>c</sub>, is one of the criteria of orthostatic stability, since an increase in variability of RVG<sub>c</sub> parameters, along with decline to one-third to one-half of RI in cerebral vessels, is a precursor of a syncopic state [13].

Recording the REG in the frontomastoid lead enables us to determine the dynamics of blood supply to the brain in the region of the motor and auditory analyzers. Functional asymmetry of the regions of the brain studied is 75-85% attributable to motor asymmetry, which is right-sided in the vast

majority of cases [14]. The fact that tonus was lower in the vessels of the right extremities in subjects with left-sided asymmetry of brain filling indicates that motor asymmetry makes an appreciable "contribution" to asymmetry of filling of the brain. However, filling asymmetry is apparently not determined solely by functional asymmetry, but also by specialization of functions of the cerebral hemispheres [15], since we found that there were only a few more subjects with left-sided asymmetry of brain filling than with right-sided asymmetry. The "reaction" to orthostatic factors of parameters of the dominant (according to filling with blood) hemisphere was more stable in degree and direction; the REG parameters of this hemisphere retained individual distinctions to a greater extent with change in position of the body. Asymmetry of filling should probably be taken into consideration when evaluating REG parameters during orthostatic and other functional tests.

The results of these investigations indicate that rheographic parameters are highly informative in determining man's orthostatic stability.

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EFFECT OF REDISTRIBUTION OF BLOOD ON SEVERITY OF SPATIAL POSITION ILLUSIONS  
IN WEIGHTLESSNESS

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[Article by F. A. Solodovnik, A. V. Chapayev, A. A. Prusskiy and  
A. A. Simakov]

[English abstract from source] The study was performed onboard a specially equipped aircraft which allowed zero-g and high-g studies. Blood redistribution was produced using a tilt table ( $-30^\circ$ ) and a LBNP device. Illusionary sensations were measured by a Birtok unit and subjective reports of the test subjects. In the head-down position the feeling of blood rush to the head disappeared as soon as the weightless state was reached. In most cases illusionary sensations were similar to those in the horizontal position. When exposed to LBNP tests, the subjects developed no illusionary sensations during horizontal flight and felt their upper body going upwards and legs going downwards in the weightless state. Thus, illusionary sensations of the spatial position depend at large on blood redistribution in the human body.

[Text] During spaceflights, many American and Soviet cosmonauts experienced illusions referable to spatial position, as well as the feeling of blood rushing to the head [1, 2]. These sensations developed in the first hours and days of flight, and they lasted mainly up to 1 week. Many researchers believe that onset of illusionary sensations of spatial position is due to stimulation primarily of the otolith system and other afferent systems [3, 4]. However, it is believed by some authors that redistribution of blood in the cosmonaut's body could also affect their development [5].

Our objective here was to determine whether redistribution of blood in the human body affects the severity of spatial position illusions in weightlessness.

#### Methods

We conducted our studies aboard a flying laboratory [aircraft] in flights over a parabolic curve with reproduction of brief weightlessness for about

25 s. A tilt table was installed in the passenger cabin of the aircraft. There was vacuum gear on the table to create negative pressure about the lower body.

The studies in weightlessness were conducted with the subjects in horizontal and antiorthostatic ( $-30^\circ$ ) position, including low pressure about the lower body. We prepared for the tests with the aircraft flying horizontally. The subject was placed on the tilt table in the vacuum gear, and he was immobilized with regulation straps. To objectivize his sensations of spatial position, we used the Birtok instrument, the basis of which is a guiding device located in a rigid, lightproof housing (Figure 1). The guiding unit

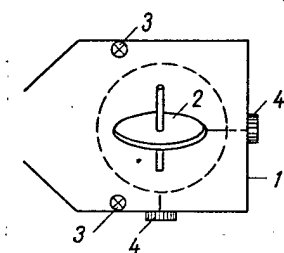


Figure 1.

Line diagram of Birtok instrument

- 1) housing
- 2) swiveling device
- 3) light for swiveling device
- 4) control knobs

consists of a horizontal disc and vertical pin. There is a light source in the housing to illuminate it. The subject positions the guiding device in two planes by means of control knobs, in accordance with his perceptions of top and bottom, and makes a mark on record charts by depressing buttons. The instrument was rigidly secured with a bracket to the head of the tilt table, and it could be placed and secured in a convenient position in the region of the upper part of the face, at the subject's eye level, by changing the relationships between its components (Figure 2).

The subjects were changed to head-down position 5 min before submitting them

to weightlessness. Negative pressure was created around the lower body either 5 min before weightlessness or after moving the subject to antiorthostatic position. The "negative" pressure in the vacuum gear constituted 50 mm Hg.

During horizontal flight, the subject set the swivel [guide] device of the instrument in accordance with his perception of top and bottom, and the experimenter fixed this position by perforating the record charts. Each subject was tested following the entire program in the course of the same flight.

After changing to weightlessness, the subject spent the first 10 s with the eyes closed, then reported his perception of spatial position in relation to the direction of what seemed to be the ceiling. He then opened his eyes and set the guiding device of the instrument to correspond to his sensations of top and bottom (if they appeared), which were recorded, under visual control by manipulating the control knobs. After weightlessness, the subject defined his sensations of spatial position. The results of subjective evaluation of spatial position were entered in the log of the studies, while the data referable to objective recording of sensations were interpreted in the laboratory and also logged. Evaluation of the nature of spatial illusions was made on the basis of subjective sensations and objective records.

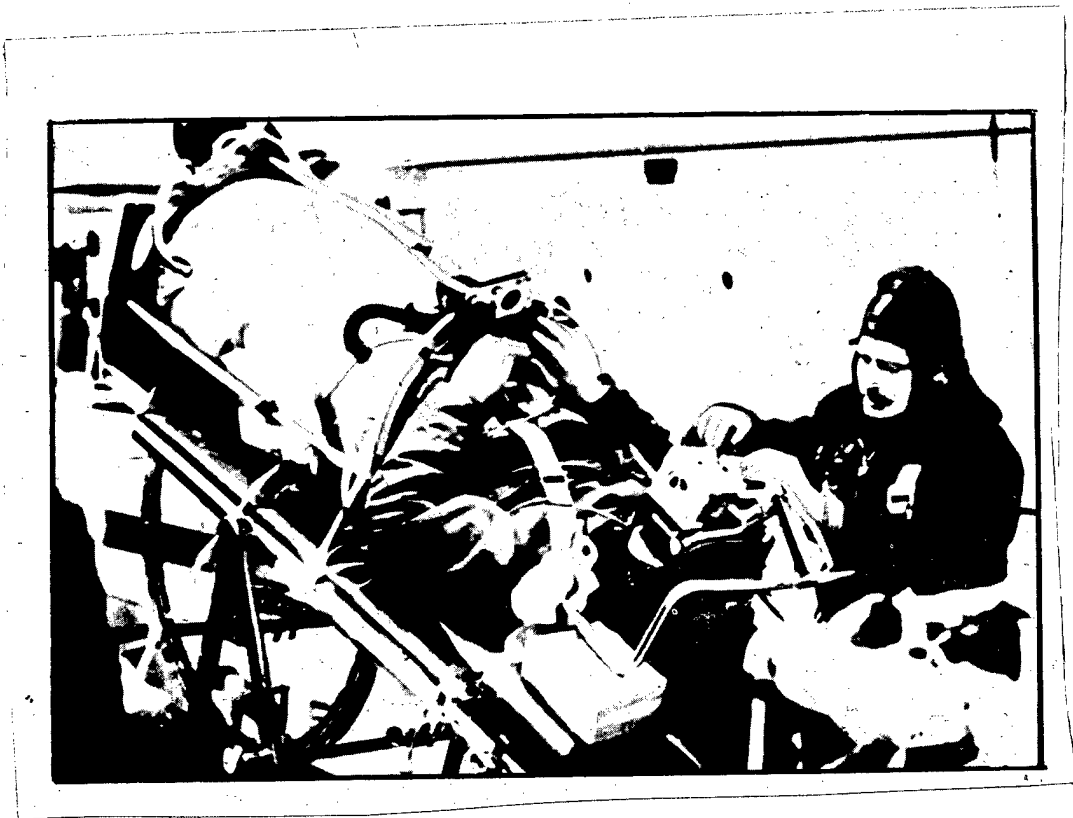


Figure 2. Test in vacuum gear on tilt-table during brief weightlessness in aircraft-laboratory

A total of 10 healthy men differing in experience of flying in weightlessness participated in these studies.

#### Results and Discussion

As indicated by the results of these studies, spatial illusions in weightlessness depended largely on the nature of redistribution of blood in the human body. With the tilt-table in horizontal position in the aircraft, under weightlessness conditions, most subjects developed illusions of the body being tilted backward. The severity of these sensations varied in different men: from mild elevation of the legs to the sensation of being upside down (Figure 3). In some cases, the illusion of being thrown backward was combined with the sensation of a tilt in the frontal plane. The same findings were made by other authors with subjects in seated and standing positions [6, 7].

In weightlessness, the illusions in antiorthostatic position ( $-30^\circ$ ) were the same in most cases as in horizontal position. However, some subjects had the illusion of the legs being dropped with some elevation of the upper part of the trunk.

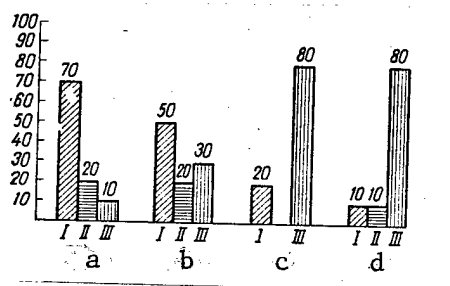


Figure 3.

Severity of spatial illusions under different test conditions in weightlessness. Y-axis, number of cases

- a) in horizontal position
- b) antiorthostatic position
- c) horizontal position with use of vacuum gear
- d) antiorthostatic position with vacuum gear
- I) illusion of body being thrown backward
- II) no illusions
- III) illusion of head being elevated and legs dropped

During horizontal flight, all of the subjects in antiorthostatic position had the sensation of blood rushing to the head, which was manifested by the feeling of bursting and heaviness. In weightlessness, all of these sensations disappeared immediately.

The redistribution of blood in the human body is probably much less marked in weightlessness than in antiorthostatic position. For this reason, with onset of weightlessness blood flows away from the top of the body, which is what apparently causes disappearance of sensations of blood rushing to the head and, in some subjects, change in nature of illusional sensations. Most probably, the change in direction of illusions in this instance depends on individual distinctions of vascular regulation when there is redistribution of blood in the body.

When creating negative pressure about the lower body in horizontal flight, the subjects perceived their position very

well and experienced no illusions, although some authors [8] did report illusional sensations of being turned head up under these conditions. Perhaps, the absence of these illusions in our tests was attributable to the following factors: legs touching the bottom of the gear, its cuffs adherent to the skin of the back and upper abdomen, attachment of shoulder straps to the gear itself and relatively brief use of negative pressure (5 min).

In weightlessness, LBNP elicited in most subjects the illusion of elevation of the upper half of the body with descent of the legs together with the tilt-table. The subjects felt that they were almost in erect position. This sensation persisted throughout the period of weightlessness, whereas after it the subjects felt that their body moved back to horizontal position.

LBNP in antiorthostatic position during horizontal flight diminished the sensation of blood rushing to the head. With onset of weightlessness, most subjects experienced the sensation of elevation of the upper body and dropping of the legs. Consequently, the rush of blood to the upper body, which appeared as a result of prior antiorthostatic position, disappeared in weightlessness, and the illusions were attributable chiefly to rush of blood to the bottom half of the body caused by negative pressure in the gear.

The mechanisms of redistribution of blood in antiorthostatic position and with LBNP are different. Thus, a rush of blood to the upper part of the body under ground-based conditions occurs under the effect of gravity. The

redistribution of blood in the body with LBNP has a different physical basis. The rush of blood to the lower half of the body, due to lower pressure around it, elicits in weightlessness illusions of vertical or close to vertical position. Similar findings were made by other authors [8]. Thus, with LBNP and concurrent change in position in weightlessness, the subjects retained the same idea about top and bottom as on the ground. But the methodological procedure used by the authors did not enable them to detect a change in nature of illusions in weightlessness with artificially induced redistribution of blood in the human body, as we did in our studies.

As can be seen in Figure 3, not all of the subjects presented the same direction of illusions in weightlessness with artificially induced redistribution of blood. The existing differences are probably related to distinctions of hemodynamic regulation and, perhaps, of function of different afferent systems, mainly the vestibular analyzer.

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FREE AMINO ACIDS OF BLOOD BEFORE AND AFTER SHORT-TERM SPACEFLIGHTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 2 Jun 82) pp 43-45

[Article by T. F. Vlasova, Ye. B. Miroshnikova and A. S. Ushakov]

[English abstract from source] The amino acid composition of plasma and serum of the crewmembers who performed short-term flights (of 3 to 14 days) onboard the Salyut-6 orbital station was investigated. Immediately postflight total amino acids remained unchanged while variations in isolated amino acids (tendency toward increased aspartic acid and decreased cystein in plasma, and increased leucin in serum) were adaptive.

[Text] Studies of recent years indicate that the conditions prevailing in manned spaceflights lead to some changes in the free amino acid pool of peripheral blood, the severity of which depends on flight duration [1-3]. For this reason, we investigated here the levels of plasma and blood serum free amino acids in crewmembers of visiting missions who participated in flights lasting 3 to 14 days, to go to the Salyut-6 orbital station.

Methods

Concentrated levels of free amino acids in plasma and blood serum collected on a fasting stomach from the ulnar vein were assayed using the method of ion-exchange chromatography on automatic analyzers (KLA-3V, Hitachi, Liquimat III, Labotron) with preliminary deproteinization using sulfosalicylic acid [4-6]. We examined 15 cosmonauts before and on the 1st day after flights differing in duration, the parameters being assayed in plasma in 11 of them and blood serum in 4.

Results and Discussion

The Table lists data on free amino acid levels in the tested physiological fluids, including the physiological norm for cosmonauts which we listed for serum (n = 10) and plasma [1]. The Table did not include data on blood levels of lysine, histidine and arginine, since they were not assayed in all crew members. As can be seen from the data listed in this table, pre-flight levels of free amino acids in cosmonauts' blood plasma were virtually the same as the norms that we determined previously. The only

exceptions were the high threonine content ( $P < 0.05$ ) and low glutamic acid ( $P < 0.001$ ). The changes in concentrations of these amino acids had an insignificant effect on total amino acids of blood plasma before the flight, which constituted 18.1 mg%, versus the norm of 19.2 mg%. In view of the demonstrated changes in blood plasma threonine and glutamic acid levels, we compared the results obtained on the 2d postflight day to values obtained just prior to the flight that had been submitted to statistical processing. A comparison of postflight data on amino acid composition of blood serum was also made to preflight data in view of the discrepancy in tyrosine content ( $P < 0.05$ ). Data on levels of free amino acids in plasma and blood serum of cosmonauts were submitted to statistical processing for all the flights.

Free amino acid content ( $\mu\text{g}\%$ ) of cosmonauts' blood plasma and serum before and after flight

AMINO ACID	PLASMA			SERUM		
	PHYSIOL. NORM FOR COSMONAUTS ( $n = 10$ )	PRE-FLIGHT ( $n = 11$ )	POST-FLIGHT ( $n = 11$ )	PHYSIOL. NORM FOR COSMONAUTS ( $n = 4$ )	PRE-FLIGHT ( $n = 4$ )	POST-FLIGHT ( $n = 4$ )
ISOLEUCINE	$0.77 \pm 0.13$	$0.63 \pm 0.05$	$0.85 \pm 0.06$	$1.03 \pm 0.10$	$1.00 \pm 0.04$	$1.57 \pm 0.38$
LEUCINE	$1.48 \pm 0.10$	$1.30 \pm 0.08$	$1.49 \pm 0.11$	$2.09 \pm 0.11$	$2.05 \pm 0.14$	$3.14 \pm 0.24$
VALINE	$2.33 \pm 0.10$	$1.90 \pm 0.05$	$2.39 \pm 0.54$	$2.72 \pm 0.03$	$2.63 \pm 0.04$	$3.26 \pm 0.48$
THREONINE	$2.56 \pm 0.13$	$3.27 \pm 0.25$	$3.79 \pm 1.07$	$2.25 \pm 0.12$	$2.22 \pm 0.14$	$1.67 \pm 0.24$
SERINE	$1.34 \pm 0.07$	$1.24 \pm 0.10$	$1.56 \pm 0.32$	$3.95 \pm 0.29$	$4.91 \pm 0.48$	$4.28 \pm 0.35$
METHIONINE	$0.26 \pm 0.01$	$0.25 \pm 0.04$	$0.26 \pm 0.07$	$0.68 \pm 0.15$	$0.56 \pm 0.13$	$0.58 \pm 0.15$
TYROSINE	$0.80 \pm 0.05$	$0.74 \pm 0.05$	$0.85 \pm 0.22$	$0.93 \pm 0.20$	$1.69 \pm 0.24$	$1.51 \pm 0.19$
PHENYLALANINE	$0.73 \pm 0.04$	$1.00 \pm 0.09$	$0.91 \pm 0.19$	$1.60 \pm 0.15$	$1.69 \pm 0.25$	$1.68 \pm 0.28$
CYSTINE	$0.73 \pm 0.04$	$0.56 \pm 0.06$	$0.41 \pm 0.17$	$2.76 \pm 0.30$	$2.68 \pm 0.40$	$2.67 \pm 0.65$
ASPARTIC ACID	$0.11 \pm 0.01$	$0.15 \pm 0.02$	$0.18 \pm 0.11$	$1.10 \pm 0.05$	$1.01 \pm 0.03$	$1.01 \pm 0.93$
GLUTAMIC ACID	$2.01 \pm 0.10$	$1.39 \pm 0.10$	$1.53 \pm 0.79$	$4.39 \pm 1.00$	$5.09 \pm 1.97$	$5.03 \pm 1.90$
PROLINE	$2.28 \pm 0.07$	$2.11 \pm 0.12$	$2.03 \pm 0.26$	$2.42 \pm 0.20$	$2.56 \pm 0.24$	$3.30 \pm 0.71$
GLYCINE	$1.32 \pm 0.09$	$1.35 \pm 0.04$	$1.56 \pm 0.26$	$2.35 \pm 0.18$	$2.51 \pm 0.31$	$2.55 \pm 0.19$
ALANINE	$2.44 \pm 0.10$	$2.23 \pm 0.14$	$2.89 \pm 0.47$	$4.36 \pm 0.15$	$4.22 \pm 0.14$	$4.22 \pm 0.12$

On the 1st day after short-term flights, the free amino acid pool of blood plasma increased insignificantly (to 20.7 mg%, the inflight deviation constituting +2.6). The concentrations of most of the tested amino acids remained at preflight levels, and we only observed a tendency toward decline of cystine ( $P > 0.05$ ) and elevation of aspartic acid ( $P > 0.05$ ). Blood serum showed a reliable increase in leucine concentration ( $P > 0.01$ ), which led to insignificant increase in overall free amino acid content (to 37.7 mg%; +2.9 change during the flight).

The changes demonstrated in levels of some amino acids of blood plasma (tendency toward decline of cystine and elevation of aspartic acid) and blood serum (elevation of leucine) on the first day of readaptation to ground-based conditions were apparently related to adaptive reactions. It



must be noted that in a previous study [1], we demonstrated that a 2-day flight caused virtually no change in amino acid composition of cosmonauts' blood, with the exception of decline of glutamic acid level. With increase in flight duration to 8 days, there was a decrease in concentrations of most tested free amino acids in blood. The differences demonstrated in the amino acid spectrum of cosmonauts' blood in this study, as compared to those found previously [1] are most probably attributable to the nonidentical conditions of the short-term flights and, in addition, the more refined habitat aboard the Salyut-6 orbital station.

Thus, studies of amino acid composition of blood plasma and serum of crews involved in visiting expeditions, who flew to the Salyut-6 orbital station, indicate that flights lasting 3 to 14 days have virtually no effect on the tested parameters of amino acid metabolism in blood, while the insignificant changes in levels of some amino acids are adaptive.

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CHANGES IN BLOOD UREA CONTENT UNDER HYPOKINETIC CONDITIONS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 28 Sep 82) pp 45-48

[Article by I. S. Balakhovskiy and T. A. Orlova]

[English abstract from source] The blood and urine content of urea and creatinine, as well as urea production and creatinine clearance were measured in 9 test subjects exposed to head-down tilting (at  $-6^{\circ}$ ) for 8 days. The trend for an increased urea content was more marked in the test subjects with its initially low concentration (3.3-4.2 mmol/l). Variations in the urea concentration were similar and included its decrease during the first day and increase thereafter. Creatinine excretion and clearance declined uniformly and significantly during the first 5 experimental days. No correlation was found between urea concentration and urea production, or between creatinine clearance and urea concentration.

[Text] Restricted mobility, both in the case of bed rest or being in small chambers, often leads to increase in blood urea content. We described this phenomenon as far back as 1969, and it was subsequently confirmed by other researchers [1, 2, 3]. During spaceflights, blood urea content also increases often [2, 4], and for this reason bed rest is an adequate model of weightlessness in this respect.

We made an attempt here to find an explanation for this phenomenon, by means of daily assays of urea and creatinine levels in urine and blood in the course of 8 days of strict bed rest, using the existing conceptions of the mechanism of excretion of urea by the kidneys.

Methods

We conducted three series of studies: main, additional and control. In the main series, 5 young healthy males spent 7 days under hypokinetic conditions in antiorthostatic position with a  $-6^{\circ}$  tilt.

Blood was taken daily for analyses at 0900 by puncturing a finger. We designated the sample taken on the day the experiment began as "before experiment," the one taken on the following day as "1st day," etc. Urine

was collected in 4-h batches in the daytime and 12-h batches at night. There were 4 subjects used in the additional series, and they remained for 5 days on bed rest, also at a tilt angle of  $-6^{\circ}$ . Their blood was analyzed twice (before and after the experiment) and urine was analyzed daily.

The control series included findings on 8 healthy young men whose motor activity was unrestricted; some of them were given a protein supplement, in the form of cottage cheese, in addition to the usual food allowance, which was the same in all three series. Since we found that the tested loads did not affect blood urea content, when assayed at 0900 hours, we deemed it possible to combine subjects who did and did not receive cottage cheese in the same control group.

Blood urea was assayed by the diacetylmonoxime method in blood samples dried on paper filters [2]; blood creatinine was assayed by means of a micromodification of the Jaffe reaction after isolation on ion-exchange resin [5]; urine urea was assayed by the reaction with paradimethylaminobenzaldehyde [6] and urine creatinine by the reaction with picric acid.

## Results and Discussion

In the two series of studies we are describing, as well as findings made previously during spaceflights or under hypokinetic conditions [2, 4], blood urea level rose often, but not always. Thus, in the additional series, where 4 subjects participated, the base urea level was high, averaging 6.42 mmol/l, and ranging from 5.5 to 7.0 mmol/l; after the experiment it showed virtually no change: average 6.40 mmol/l and range of 5.5 to 6.8 mmol/l. The findings were different in the main series, where base urea content, before the experiment, constituted 3-3-4.2 mmol/l. As can be seen in the Figure and Table, the blood urea concentration increased consistently throughout the observation period. These findings enabled us to derive a preliminary conclusion that the tendency toward increase in blood urea content is more typical for individuals with initially low content.

It should be noted that the higher urea concentration in subjects who made up the additional group coincided with more intensive nitrogen metabolism: while mean daily urea excretion constituted 371 mmol in the main series, it was 584 mmol in the additional one, i.e., 57% higher. At the same time, there was insignificant difference in mean daily creatinine excretion: 14.1 mmol in the main group and 15.8 mmol in the additional one, i.e., only 12% more. Thus, we find that subjects who excrete more urea also present a higher blood urea content, which is in contradiction with our older data [7]. Perhaps this is due to differences in experimental conditions: in the former case we compared the mean urea concentration over a 24-h period and excretion for the same 24 h, whereas in the latter we were dealing with longer periods of time.

The Figure illustrates the results of assaying urea and creatinine content of blood in subjects referable to the main and control series. Since blood urea content is in the narrow range of the individual norm for each healthy person [8], we showed the urea parameters expressed for each subject as a percentage of the mean, i.e., obtained as a result of averaging all of the tests. As can be seen, the dynamics were very similar in 4 subjects of the main series (who

Dynamics of biochemistry of blood and urine, as well as creatinine clearance under hypokinetic conditions ( $\bar{x} \pm m$ )

PARAMETER	MAIN SERIES (n=5)										CONTROL SERIES (n=8)			
	BEFORE STUDY	DAY OF OBSERVATION									1	2	3	4
		1	2	3	4	5	6	7						
BLOOD UREA MMOL/L	3,88 ± 0,16	3,20 ± 0,14	3,20 ± 0,26	4,02 ± 0,27	4,08 ± 0,21	3,80 ± 0,26	4,42 ± 0,17	4,54 ± 0,31	4,36 ± 0,28	4,28 ± 0,23	4,60 ± 0,24	4,70 ± 0,27		
BLOOD CR MOL/L	119 ± 22	116 ± 6	122 ± 8	127 ± 4	124 ± 2	128 ± 5	125 ± 4	131 ± 7	102 ± 7	106 ± 8	111 ± 6	106 ± 6		
UREA PRODUCTION MMOL/DAY	286 ± 29	385 ± 24	377 ± 45	370 ± 39	300 ± 42	428 ± 54	467 ± 64	386 ± 47	—	—	—	—		
CR EX MMOL/DAY	13,2 ± 1,34	17,8 ± 0,96	10,9 ± 1,18	10,5 ± 1,33	10,7 ± 1,77	13,8 ± 2,05	16,3 ± 1,13	16,4 ± 1,11	18,4 ± 0,8	17,6 ± 1,2	17,5 ± 1,5	15,6 ± 1,7		
DT CR CL ML/MIN	123 ± 16	114 ± 18	94 ± 7	87 ± 14	55 ± 6	101 ± 16	103 ± 9	91 ± 12	141 ± 45	130 ± 29	112 ± 39	151 ± 52		
NUMBER OF SPECIMENS	13	13	14	14	15	11	15	14	23	23	24	23		
NT CR CL ML/MIN	66 ± 18	103 ± 9	38 ± 12	39 ± 9	62 ± 12	64 ± 9	79 ± 12	74 ± 12	117 ± 13	106 ± 11	108 ± 11	116 ± 10		
NUMBER OF SPECIM.	4	5	5	5	5	4	5	5	8	8	8	8		
DT UREA MMOL/L	383 ± 35	465 ± 36	420 ± 28	427 ± 23	324 ± 31	475 ± 53	349 ± 37	501 ± 36	465 ± 21	500 ± 27	525 ± 34	582 ± 36		
NUMBER OF SPECIM.	13	13	15	14	15	14	15	14	24	24	24	24		
NT UREA MMOL/L	330 ± 23	512 ± 68	438 ± 45	437 ± 46	220 ± 46	546 ± 90	562 ± 32	544 ± 127	522 ± 35	524 ± 37	620 ± 44	555 ± 58		
NUMBER OF SPECIM.	4	5	5	5	5	5	5	5	8	8	8	8		
DAILY DIURESIS	937 ± 168	803 ± 90	898 ± 151	1170 ± 181	859 ± 75	948 ± 114	700 ± 30	1398 ± 48	1354 ± 104	1147 ± 107	1180 ± 106			

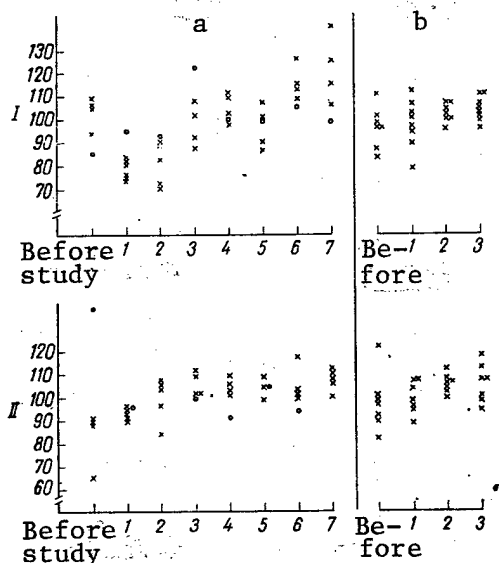
Key: CR) creatinine EX) excretion CL) clearance NT) nighttime DT) daytime  
CN) concentration

are designated with x's) and characterized by a decline during the 1st day with subsequent elevation for the duration of the experiment, so that at the end the concentration was reliably higher than at the beginning (see Table). Creatinine concentration in blood of these subjects changed negligibly.

The only exception was subject S. (circles). On the 3d day of the study he complained of pain in his nose, and it was diagnosed as a developing furuncle. The head of the bed was elevated somewhat for 1 day and the patient was given antibiotics; the test was resumed when there were no more complaints. It should be noted that S. differed from the other subjects in a number of metabolic parameters, including dynamics of blood urea and creatinine concentration (see Figure). It is unclear whether these differences could be attributed to diminished immune resistance, as indicated by the furuncle, or whether there were also some other causes.

The Figure and Table contain data obtained on 8 subjects of the control series who maintained their normal motor activities. As we see, there was considerably less scatter of blood urea concentrations than in the main series. At the same time, the dynamics of creatinine concentration in blood were similar in the two groups. Thus, many subjects showed an increase in blood urea concentration under hypokinetic conditions that exceeded considerably any possible chance fluctuations.

We determined urea production as the sum of excreted and accumulated urea. In calculating the latter,



Concentration of urea (I) and creatinine (II) of blood (% of mean values).

X-axis, day of study; y-axis, percentage

- a) main group
- b) control
- x) blood urea and creatinine content in main and control groups
- o) analogous parameters in subjects with different dynamics of blood urea and creatinine concentration

creatinine clearance, a comparison of individual parameters does not enable us to draw an unequivocal conclusion as to the cause and effect link between the decrease in creatinine clearance and increase in urea concentration, nor can we offer the unequivocal explanation that the increase in urea is due to increased production.

Urea retention could also have been caused by renal incapacity to concentrate it to levels, at which existing diuresis would provide for all of the formed urea to be excreted in urine. However, according to data in the table, under hypokinetic conditions renal concentrating capacity is not impaired. In daytime urine specimens, urea concentration remained high and showed virtually no difference from control levels or from the results we previously observed in other studies.

Thus, we did not succeed in establishing any definite and unequivocal cause for the increase in blood urea content under hypokinetic conditions. The

we proceeded from the fact that the urea space of each of our subjects was 50 l (i.e., about two-thirds of body mass, which ranged from 70 to 80 kg in these subjects). This figure was multiplied by the change in urea concentration in the tested day, and the product was added algebraically to excreted urea. Retention never exceeded 25% of the excreted amount and was usually under 10%. We found that there was less urea production on the first experimental days than on subsequent ones, but at the same time it was subject to significant inconsistent fluctuations. We failed to demonstrate a reliable correlation between urea production and increase in its level in blood.

Daily excretion of creatinine, as well as its clearance, fluctuated over a wide range throughout the study. However, if we average the values obtained in analyses of urine specimens collected only in the daytime, we find a very definite pattern: reliable decline for the first 5 days of hypodynamia. At night the findings were not as consistent. In a number of instances, what was retained in the daytime was excreted at night; but there were not many night batches, so that it is difficult to draw a reliable conclusion. In spite of the fact that, on the whole, the tendency toward increase in blood urea coincides with a tendency toward decrease in

impression is gained that we are dealing with very minimal disbalance between production and excretion, which is referable to the category of functional regulatory disturbances. Indeed, in a person weighing 75 kg who produces 400 mmol urea per day and in whom the urea space is 50 l, retention of 50 mmol urea leads to a 1 mmol/l increase in its concentration in blood, i.e., by an amount that we consider to be a reliable increase. At the same time, this is only one-eighth of the daily production, and daily production may vary considerably.

In this regard, a more general question arises: How does the body manage to maintain a constant blood urea level even though both its production and excretion, as well as concentration in urine, fluctuate considerably. In our preceding studies we already were able to demonstrate that the fluctuations in blood urea concentration in healthy man usually do not exceed  $\pm 0.3$  mmol/l and that neither brief restriction of protein intake nor protein loads are capable of altering it for a long time.

According to the popular filtration-reabsorption theory, urea is first filtered in the glomerules then reabsorbed in the tubules. For this reason, its level in blood should be regulated by either the former or latter process. Under physiological conditions (i.e., with healthy kidneys), there is no parallel between urea and creatinine clearance, or between concentrations of these substances in blood; for this reason, the magnitude of glomerular filtration cannot be the regulator of blood urea concentration. It remains to be assumed that this concentration is regulated by means of changes in permeability of the tubular wall and thereby the share of reabsorbed urea. However, a more thorough examination reveals that this possibility is also very unlikely, since the urine urea concentration is considerably greater in most cases than osmolarity of blood, and it sometimes exceeds the latter by 2.5 times. If we were to adhere strictly to filtration-reabsorption theory, we must agree that the high osmotic concentration of urine urea is created because of removal from it of osmotically free water, i.e., that water is actively reabsorbed from tubular fluid. However, existence of active water transport has not yet been proven in any system, and at the present time all authors agree that it is only passively displaced after the displacement of salts. It remains for us to accept the thesis that urea is actively secreted in the tubules, although a strong enough mechanism of its active transport cannot be demonstrated either on the cellular or tissular level [8]. Considering all these difficulties, most authors believe that a high concentration of urea in urine is created because of the existence of some complex and not very understandable mechanism, which is arbitrarily called counterflow-multiplier. Apparently, its principal function is to remove urea from the body (rather than some abstract "osmotically active substances"). Expressly changes in function of this mechanism should be used to explain the fluctuations of blood urea concentration. However, both the nature of receptors sensitive to changes in blood urea concentration and structure of reflex, as well as the concrete route of its impairment under hypokinetic conditions, remain absolutely unclear.

Thus, this comprehensive study enabled us to establish only that, under hypokinetic conditions, there is an increase in urea content and decrease in

creatinine clearance, but the cause and effect link between these parameters has not been established.

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ENERGY METABOLISM ENZYMES IN SIMULATION OF SOME SPACEFLIGHT FACTORS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 28 Sep 82) pp 49-51

[Article by S. Kalandarov, V. P. Bychkov, I. D. Frenkel', L. P. Volkova and G. I. Proskurova]

[English abstract from source] The content of lactate dehydrogenase, amino transferases and creatine kinase was measured in the test subjects of three age groups (41-50, 50-57 and 26-33 years) exposed to head-down tilt, linear acceleration, exercise, and emotional stress. The enzyme activity increased in response to head-down tilt, acceleration and exercise. The enzyme content normalized under the influence of selected nutrients.

[Text] Hypokinesia is one of the adverse factors of long-term spaceflights, and it can also be associated with clinical treatment of many diseases. In addition, with increasing technological progress more and more people are subject to relative hypokinesia [1].

Several authors [1-4] believe that development of changes due to weightlessness and hypokinesia as its ground-based model is based on mechanisms such as altered conditions of motor activity, elimination of hydrostatic pressure of column of blood on the walls of the vascular system, changes in function of afferent systems. The aggregate of such primary effects of weightlessness and hypokinesia causes onset of changes in fluid-electrolyte, hormone and energy metabolism, as well as in a number of other systems and organs. The associated changes in neurohumoral regulation via enzymatic systems lead to certain changes in metabolic processes in the body [5].

There are few works dealing with investigation of enzyme activity under hypokinetic conditions. They were pursued in short-term (up to 7 days) studies. Some authors [6, 7] failed to demonstrate changes in activity of lactate dehydrogenase (LDH), alanine and aspartate aminotransferases (ALT and AST), or in creatinine kinase (CK); others [8, 9] demonstrated some increase in activity of the above-mentioned enzymes.

No studies were made of blood serum enzyme activity in people of different ages submitted to long-term antiorthostatic ( $-8^\circ$  tilt) hypokinesia (ANOH) and a combination of this factor with linear accelerations and exercise,



as well as nervous and emotional stress, and this is why we undertook the present investigations.

#### Methods

Data were obtained for 27 subjects in three age groups: first--41-50 years (10 people), second--50-57 years (11 people) and third group--26-33 years (6 people). The first and second groups of subjects were exposed to linear accelerations of 3 G for 1 min and exercise of 450-600-750-900-1050 kg-m (3 min on each level) during the period preceding ANOH, as well as after it. The third group of subjects was submitted to nervous-emotional stress before, during and after ANOH. Stress was produced by using a psychological test (performance of tasks differing in difficulty with a time limit).

LDH, AST and ALT content, as well as CK of blood serum was assayed in the first and second groups by spectrophotometry [10-12]. Quantitative assays of enzymes in the third group of subjects were made using a Chemetries (United States) biochemical analyzer. The data were compared to those obtained for healthy people.

The diet consisted of a balanced food allowance with regard to levels of the main nutrients, totaling about 3000 kcal. In addition to this food allowance, we used several nutrients for the third group of subjects to correct metabolic changes and maintain a high level of work capacity under stress. The nutrients included minerals, vitamin C, glucose and a phosphatide concentrate.

#### Results and Discussion

We demonstrated a decrease in LDH concentration ( $155.6 \pm 12.6$ ,  $P < 0.01$ ;  $150.8 \pm 21.5$ ,  $P < 0.05$ , after accelerations and ANOH, respectively) in the second group of subjects under the influence of accelerations and ANOH. In the first group, there was little difference in LDH, as compared to normal ( $200.1 \pm 4.89$  nmol/l) at all tested times. Conversely, ALT and AST levels were elevated throughout the study in the first group (normal  $72.3 \pm 8.46$  and  $58.3 \pm 5.0$  for ALT and AST, respectively), but they did not differ appreciably from the norm in the second group of subjects. There was brief elevation of CK level under the effect of graded exercise in the first group of subjects (to  $25.4 \pm 1.04$  nmol/l, versus the norm of  $20.3 \pm 1.97$ ). In the second group, the level of this enzyme was elevated throughout the observation period (Table 1).

Stress during ANOH, as well as before and after it, with intake of supplemental nutrients, had no appreciable effect on levels of the tested enzymes. There was only a brief change in amounts of some enzymes. Thus, before and after ANOH, the third group of subjects presented some increase, as compared to normal ( $90.9 \pm 6.0$  nmol/l) in LDH activity (Table 2), particularly during the period of anticipation of the stress factor. There was one increase in AST content in the recovery period ( $30.0 \pm 3.4$  nmol/l, versus the normal of  $21.8 \pm 2.1$ ,  $P < 0.05$ ).

ALT concentration decreased somewhat more under the influence of ANOH ( $17.3 \pm 1.1$  and  $16.3 \pm 1.1$  nmol/l, versus the normal  $24.5 \pm 2.55$ ). In the course

of the recovery measures, there was an increase in CK content (to  $157.0 \pm 41.3$  and  $134.5 \pm 31.5$  nmol/l, versus the normal of  $48.5 \pm 8.51$ ,  $P < 0.02$ ).

Table 1. Blood serum enzyme content (nmol/l) in first and second groups of subjects

Group	Enzyme	Before ANOH		ANOH	After ANOH	
		accelerat.	exercise		acceler.	exercise
1	LDH	$203.6 \pm 8.44$	$204.6 \pm 10.34$	$209.2 \pm 16.23$	$298.7 \pm 13.68$	$197.6 \pm 22.2$
	AST	$107.0 \pm 8.44$	$84.5 \pm 6.6$	$99.5 \pm 8.4$	$97.9 \pm 14.0$	$102.5 \pm 15.0$
	ALT	$170.8 \pm 30.9$	$147.5 \pm 16.8$	$172.8 \pm 28.3$	$207.0 \pm 39.7$	$166.7 \pm 16.8$
	CK	$21.5 \pm 0.35$	$25.4 \pm 1.04$	$18.2 \pm 1.00$	$19.1 \pm 1.19$	$20.9 \pm 1.22$
2	LDH	$155.6 \pm 12.6$	$167.7 \pm 22.9$	$150.8 \pm 21.5$	$152.4 \pm 28.3$	$173.4 \pm 35.5$
	AST	$62.2 \pm 10.9$	$60.4 \pm 7.9$	$56.6 \pm 17.4$	$54.7 \pm 8.8$	$59.8 \pm 12.6$
	ALT	$98.9 \pm 23.3$	$107.2 \pm 26.1$	$104.4 \pm 33.8$	$119.2 \pm 26.4$	$153.8 \pm 29.2$
	CK	$34.6 \pm 6.6$	$32.5 \pm 3.7$	$43.3 \pm 8.9$	$58.3 \pm 18.0$	$80.5 \pm 30.4$

Table 2. Blood serum enzyme content (nmol/l) in third group of subjects

Enzyme	Before ANOH				ANOH -8°	
	stress					
	before	after	before	after	before	after
LDH	122,0±11,8	120,2±31,8	161,0±16,0	117,0±7,9	80,0±10,1	77,0±5,1
AST	23,6±2,6	24,4±2,4	23,0±1,6	19,1±3,2	20,5±1,8	24,6±1,9
ALT	20,8±2,6	21,0±2,6	26,4±3,2	20,5±6,2	17,3±1,1	19,3±1,1
CK	78,4±11,8	90,0±15,7	112,5±30,3	105,1±31,9	59,5±27,3	64,1±34,9

Enzyme	ANOH - 8°				After ANOH	
	stress					
	before	after	before	after	before	after
LDH	75,0±8,1	76,0±5,8	83,0±8,5	82,0±6,7	161,0±38,6	141,0±25,9
AST	18,6±0,5	22,3±2,5	21,1±1,9	24,5±1,9	30,0±3,4	28,5±3,5
ALT	17,0±1,8	18,6±1,6	18,8±3,0	20,3±2,3	19,6±2,1	19,6±2,3
CK	66,6±14,0	65,0±10,5	83,3±8,5	82,2±6,7	157,0±41,3	134,5±31,5

Thus, there was a change in activity of enzymes of energy metabolism under the influence of ANOH, as well as accelerations and exercise. These changes were correlated with increased function of the adrenosympathetic system and adrenal cortex.

It has been indicated [2, 5] that metabolic changes play a substantial part in the pathogenesis of hypokinetic disorders. Catecholamines and steroid hormones, which stimulate the enzymatic system, are instrumental in

eliminating these disorders. The demonstrated changes in enzyme levels were apparently directed toward increasing the body's adaptation capacity in response to stressors in the form of ANOH, linear accelerations and exercise.

Use of additional nutrients had a normalizing effect on metabolism, in particular on activity of enzymes involved in energy supply.

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MORPHOMETRIC STUDY OF RAT ADRENAL MEDULLA DURING LONG-TERM HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 8 Jun 82) pp 51-54

[Article by A. S. Pankova and Ye. A. Savina]

[English abstract from source] Using Wood's differential staining, norepinephrine- and epinephrine-secreting cells of the adrenal medulla of 36 Wistar male rats exposed to 1 to 5.5-month hypokinesia were measured caryometrically. After 2 month hypokinesia the nuclear volume of norepinephrine-secreting cells increased significantly. After 5.5-month hypokinesia no dystrophic changes were seen in the adrenal medulla.

[Text] There have been few studies of the animal neuroendocrine system under hypokinetic conditions, and they are represented in essence by biochemical investigations. Most morphological studies have dealt with the adrenal cortex of rats submitted to hypokinesia for no more than 3 months [1-5]. There are sparse data in isolated works concerning the condition of the medulla.

Our objective here was to study the adrenal medulla of rats in the course of 165-day hypokinesia.

Methods

The experiment was conducted on male Wistar rats with initial weight of 270-300 g (70 days of age). The animals were kept for 30 to 165 days in box-cages that restricted their movements; control rats were kept freely in cages, with 5-6 animals in each. We sacrificed 6 rats at a time, from the experimental and control groups, using ether, 1, 2, 3, 4 and 5.5 months after the start of the experiment.

The adrenals from 36 experimental rats and the same number of control rats served as material for investigation. We determined body weight, absolute and relative weight of the adrenals. To assess the state of the medulla, we used differential staining of norepinephrine-secreting (NSC) and epinephrine-secreting (ESC) cells according to Wood [6]. Using an RA-6 drafting machine at a 2000× magnification, we outlined the projections of nuclei (100 each of NSC and ESC) on sections stained after Wood, measured their

diameters and determined nuclear volume in cubic micrometers using conventional techniques. We measured a total of 10,800 nuclei. At the same magnification, we outlined the projections of medullar NSC (50 cells in each case) on standard paper. The outlined cells were carefully cut out and weighed on an electronic scale. The obtained data, in milligrams, were submitted to statistical processing. The reaction with glioxylic acid was run for demonstration of catecholamines on fresh-frozen cryostat sections, and we submitted them to fluorescence microscopy [7].

## Results and Discussion

In our study of the medulla, our main purpose was differentiated demonstration of NSC and ESC, evaluation of their functional state on the basis of determining the volume of the nuclei. On preparations stained after Wood, two types of medullary cells could be seen distinctly: ESC with homogeneous, dense pink protoplasm and finer ones arranged mainly in the form of islets, and NSC with golden-yellow protoplasm. We failed to demonstrate any dystrophic changes in NSC or ESC.

Dynamics of changes in volume of nuclei of rat adrenal medullary ESC and NSC under hypokinetic conditions ( $M \pm m$ )

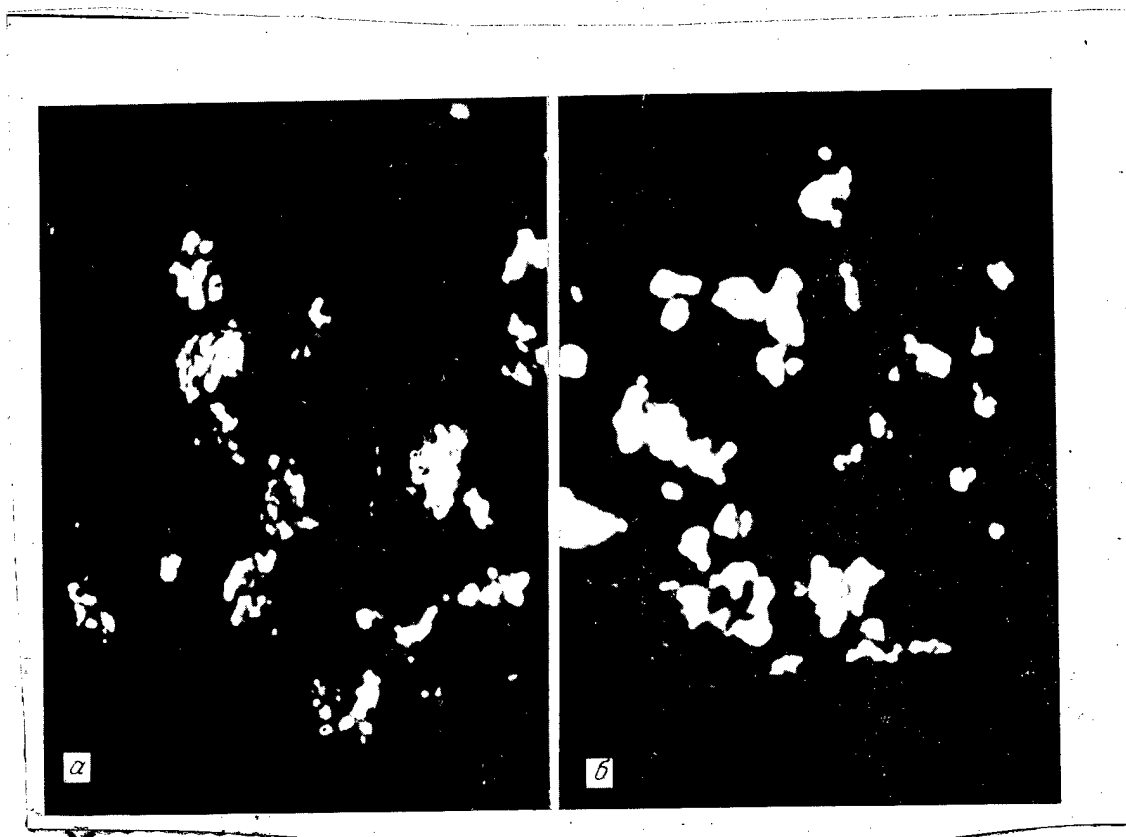
Animal group	Time of study, months	Volume of nuclei, $\mu m^3$	
		ESC	NSC
Control	1	178,3 $\pm$ 2,8	113,2 $\pm$ 8,5
	2	150,9 $\pm$ 6,5	111,8 $\pm$ 1,7
	3	175,1 $\pm$ 11,3	155,5 $\pm$ 4,6
	5 $\frac{1}{2}$	198,4 $\pm$ 5,1	169,6 $\pm$ 5,5
Experim.	1	187,0 $\pm$ 5,8	129,0 $\pm$ 9,3
	2	159,0 $\pm$ 8,1	138,1 $\pm$ 9,2*
	3	182,4 $\pm$ 4,8	164,5 $\pm$ 8,2
	5 $\frac{1}{2}$	207,9 $\pm$ 9,2	168,9 $\pm$ 3,5

\*Reliable difference ( $P < 0.02$ ), as compared to control.

5th months of the experiment failed to demonstrate significant differences from the control; we succeeded only in noting a tendency toward enlargement of NSC after 3-month hypokinesia ( $0.96 \pm 0.09$  mg in the experimental group and  $0.74 \pm 0.09$  mg in the control).

It is apparent from the results of karyometry, which are listed in the Table, that the volume of ESC nuclei of experimental rats did not differ reliably from the control throughout the experiment. At the first two experimental stages, the NSC nuclei were appreciably larger than control nuclei: after 1 month their volume increased by 14% and after 2 months, by 24% (differences are reliable). Further increase in duration of the experiment led to normalization of volume of NSC nuclei.

Examination of histological preparations failed to reveal appreciable differences in quantity, size of NSC islets or intensity of their staining at most tested times; it is only in the 2d month of hypokinesia that the impression was gained that there was enlargement of islets and NSC in them. One could assess hypertrophy of NSC by the distribution of nuclei in the islets, since we were unable to sketch the outlines of projections of the cells proper because their margins were indistinct in both groups. By the 3d month of the experiment, fine connective tissue fibers (stained light blue with aniline dye) among the islet cells in the animals of compared groups, which emphasized the cell margins. Weighing the outline projections of cells in the 3d and



Fluorescence and histochemical demonstration of norepinephrine in rat adrenal medulla (method with glyoxylic acid, magnification 200x)

- a) norepinephrine islets in control rat medulla
- b) accumulation of norepinephrine in experimental rat medullary cells with 2-month hypokinesia

Analysis of karyometric data revealed that the volume of ESC and particularly NSC nuclei increased with age in control and experimental animals, and the differences in size of nuclei of both types of cells between the 30th and 165th days of observation were reliable, both in the experiment and the control ( $P < 0.01$ ), with the exception of ESC in the experimental group.

The above data could serve as confirmation of those in [8], which reported an increase with age in activity of catecholamine-synthesizing enzymes and catecholamine content of the medulla.

Enlargement of volume of medullary cell nuclei with age must be taken into consideration in assessing morphometric data. In other words, one should have control animals of the same age for each experimental group in order to obtain correct results from long-term experiments on growing animals.

Fluorescence microscopy (reaction with glyoxylic acid) at different stages of hypokinesia (particularly after 2 months) revealed more intensive fluorescence of islets of cells containing norepinephrine and enlargement of fluorescent islets (see Figure). By the 3d-5th month, these differences disappeared. The more intensive fluorescence of NSC, combined with reliable increase in nuclear volume, is indicative of an increase in their functional activity after 2-month hypokinesia.

Thus, differentiated demonstration of ESC and NSC, and separate measurement of nuclei revealed that the above types of cells differ in their reactions for the first 2 months of hypokinesia: the size of ESC nuclei reverts to normal after 1 month of hypokinesia, while the volume of NSC nuclei reaches the control level only 3 months from the start of the experiment. If we proceed from the data in the literature, which indicate that the most marked activation of medullary function and, particularly, ESC occurs at the earlier stages of hypokinesia [9], normalization of volume of ESC nuclei occurs faster, while morphological signs of increased functional activity of NSC persist for a longer time. Unfortunately, data concerning morphological investigation of the medulla under hypokinetic conditions are submitted only in a few works, and even there either no karyometry was done, or else the volume of nuclei was measured for all medullary cells, rather than separately for NSC and ESC. Nevertheless, in the case of 56-day hypokinesia, using hematoxylin and eosin stain, there was (visual) demonstration of enlargement of medullary cells and increase in quantity of secretory granules in them. On this basis, the authors arrived at the conclusion that there is increase in activity of the medulla in the course of 56-day hypokinesia [10]. An increase in volume of medullary cell nuclei was reported [11] on the 3d, 45th and 60th days of hypokinesia. The author of the cited work concluded that the adrenal medulla was stimulated in the course of 2-month hypokinesia.

Consequently, with regard to the medulla for the first 2 months of hypokinesia, the existing morphological studies report the unanimous conclusion that its function increases. The question of state of the adrenal medulla of animals submitted to hypokinesia for longer periods of time has been studied even less, and it is debatable. In the above-mentioned work [11], it was shown that prolonging hypokinesia to 90 days leads to depletion of the medulla. In our experiment (judging from the same tendency toward increase in volume of NSC and ESC nuclei in experimental and control animals with age, identical size of NSC and absence of dystrophic changes), no morphological signs of depletion of the medulla were demonstrable at late (3-5 months) stages of hypokinesia. The results of different biochemical tests during experiments involving long-term hypokinesia also speak against depletion of medullary function. In particular, it was demonstrated [12] that there was 3-fold increase in blood epinephrine content and 2-fold increase in norepinephrine, as compared to control levels, after 70-170-day hypokinesia. In our opinion, these findings are more indicative of retention of reserve capacities of the medulla during long-term hypokinesia, rather than constant elevation of catecholamine levels. If we were to proceed from the fact that any method of taking blood (with the exception of chronic cannulation of the caudal artery) elicits immediate and significant increase in blood catecholamine content [13, 14], the increase in their levels in rats after hypokinesia,

as compared to the control, could also be viewed as an indicator of greater readiness of the medulla for a response to additional factors (in this case, the procedures of taking blood). There would not be such release of catecholamines into blood with depletion of medullary function in the course of long-term hypokinesia.

Thus, on the basis of a morphometric study (karyometry, gravimetric measurement of NSC size) and reaction with glioxylic acid during the period between the 30th and 60th days of hypokinesia, signs of stimulation of NSC function were demonstrated at later stages of the experiment. We failed to demonstrate either signs of activation of the medulla or depletion of its function. Evidently, there is stabilization of medullary function between the 90th and 165th days, i.e., the rats adapt to experimental conditions.

In conclusion, it should be noted that the discrepancies in evaluating the functional state of the adrenal medulla under hypokinetic conditions, with respect to both morphological and biochemical studies [9, 12], could be attributable to differences in methodology of the studies and nonstandard experimental conditions--different degrees of restriction of motor activity, isolation of animals and other factors.

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EFFECT OF ELEUTEROCOCCUS EXTRACT ON RECOVERY PROCESSES IN RATS FOLLOWING SEVEN-DAY HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct. 83 (manuscript received 20 Jul 82) pp 55-58

[Article by E. I. Khasina, I. V. Dardymov and I. I. Brekhman]

[English abstract from source] Rats were housed in small cages for 7 days and then were placed into regular cages. The hypokinetic animals lagged behind the controls in their weight gain and reached their normal weight 45 days after the exposure. The hypokinetic exposure stimulated the pituitary-adrenal system, the effect being most pronounced during the first 12 h after the experiment. The hypokinetic effect decreased the glycogen content and the hexokinase and glucose-6-phosphate dehydrogenase activity and increased lactate dehydrogenase and phosphoenol pyruvate carboxykinase activity. The parameters examined returned to normal 45 days after the experiment. The eleuterococcus preparation, the administration of which began immediately after the exposure, expedited the normalization of the parameters almost twofold (by day 20).

[Text] Investigation of theoretical aspects of recovery processes following long-term severe hypokinesia and their deliberate regulation is a pressing problem of space biology and clinical medicine. We submit here the results of a study of recovery processes following 7-, 20- and 90-day hypokinesia and correction of biochemical changes by means of eleuterococcus extract (*Eleutherococcus Senticosus* Maxim). We previously demonstrated that eleuterococcus extract, which does not alter the direction of biochemical changes during long-term hypokinesia, affects their intensity and prolongs the resistance stage [3]. There are publications indicative of stimulation of work capacity by eleuterococcus under hypokinetic conditions [4, 5]. We submit here data on speed of recovery following 7-day hypokinesia.

#### Methods

We conducted 2 series of experiments on 192 male Wistar rats with initial weight of  $150 \pm 1.2$  g. We used 2 groups of animals: one intact and one after 7-day hypokinesia. In each of the 10 recovery stages, we used 3 groups of rats: intact, control with recovery and with recovery in the presence of eleuterococcus. There were six animals per group, and intact animals were of the same age as those that were sacrificed.

Hypokinesia was produced by keeping the animals in individual box-cages, which restricted their movements severely. All of the animals were on the same diet. After removal of alcohol, eleuterococcus extract was given intraperitoneally twice a day (0900 and 1800 hours) in a dosage of 1 ml/kg after termination of hypokinesia; the rats were not given this extract on the day they were sacrificed.

The following served as parameters of recovery: animals' weight, relative weight of adrenals and their cholesterol content [6], glycogen level, activity of hexokinase (HK), glucose-6-phosphate dehydrogenase (GPDH), lactate dehydrogenase (LDH) in the liver and gastrocnemius, phosphoenolpyruvate carboxykinase (PEPCK) content of the liver [7-11]. The obtained data were submitted to processing by the method of variation statistics using Student's criterion.

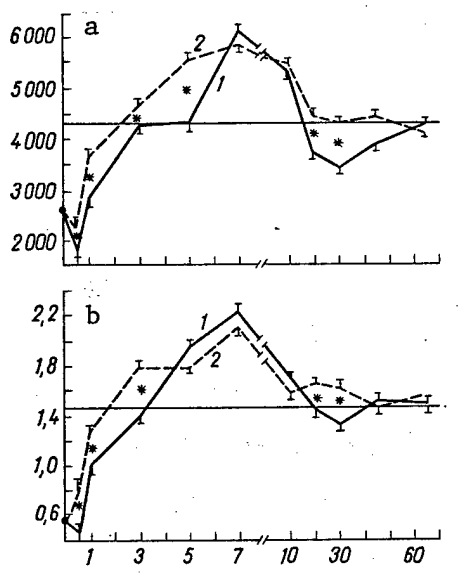
### Results and Discussion

Seven-day hypokinesia had an appreciable effect on the condition of the rats and metabolism of their tissues. The animals lost 46 g, whereas intact animals gained 12.2 g in the same period (control 116.7 $\pm$ 3.1 g, intact 162.1 $\pm$ 1.5 g). Immediately after hypokinesia, relative weight of the adrenals was 32% higher than normal (26.7 $\pm$ 0.3 mg/100 g, intact rats 20.2 $\pm$ 0.4 mg/100 g). Adrenal cholesterol level was 24% lower than in intact animals (18.4 $\pm$ 1.0 and 24.2 $\pm$ 1.0 mg/g, see Table). The tested parameters of carbohydrate metabolism in the liver were as follows at this time: glycogen 61%, HK 56%, GPDH 40%, LDH 115% and PEPCK 137% of normal, which was indicative of activation of glycogenolysis, glycolysis and gluconeogenesis, as well as depression of glucose oxidation via the pentose-phosphate pathway (Figures 1 and 2). Such changes are confirmed in numerous studies, which were summarized in the surveys by I. V. Fedorov [2], Ye. A. Kovalenko and N. N. Gurovskiy [1].

Effect of eleuterococcus extract (EE) on weight of animals and adrenal cholesterol content in the course of recovery (R) after 7-day hypokinesia

Stage of R, days	Animals' weight, g			Cholesterol, mg/g		
	normal	R	R+EE	normal	R	R+EE
1/2	162.1 $\pm$ 1.5	119.9 $\pm$ 2.0*	118.3 $\pm$ 2.1	24.2 $\pm$ 1.0	12.6 $\pm$ 0.7*	18.2 $\pm$ 1.2*
1	165.7 $\pm$ 2.8	116.0 $\pm$ 1.8*	121.0 $\pm$ 1.3	21.3 $\pm$ 1.2	13.6 $\pm$ 0.8*	18.3 $\pm$ 1.1*
3	172.5 $\pm$ 1.9	117.3 $\pm$ 7.9*	125.8 $\pm$ 1.5*	22.8 $\pm$ 0.9	20.6 $\pm$ 1.2	23.7 $\pm$ 1.1
5	175.6 $\pm$ 2.5	114.1 $\pm$ 2.1*	154.5 $\pm$ 3.9*	20.9 $\pm$ 0.5	21.3 $\pm$ 0.5	22.6 $\pm$ 0.8
7	175.1 $\pm$ 3.1	136.6 $\pm$ 4.1*	155.8 $\pm$ 3.5*	23.3 $\pm$ 1.3	27.7 $\pm$ 0.9*	23.8 $\pm$ 0.9*
10	179.1 $\pm$ 4.2	152.2 $\pm$ 3.8*	171.9 $\pm$ 4.0*	20.1 $\pm$ 1.2	24.3 $\pm$ 0.9*	19.9 $\pm$ 1.3*
20	187.3 $\pm$ 4.1	172.3 $\pm$ 3.5*	194.8 $\pm$ 4.8*	21.8 $\pm$ 0.8	19.6 $\pm$ 0.7	22.5 $\pm$ 1.3
30	195.7 $\pm$ 5.0	180.0 $\pm$ 3.9*	199.6 $\pm$ 5.1*	22.2 $\pm$ 0.6	20.0 $\pm$ 0.8	21.8 $\pm$ 0.9
45	237.3 $\pm$ 6.2	237.9 $\pm$ 4.2	234.9 $\pm$ 3.2	20.7 $\pm$ 0.7	20.1 $\pm$ 0.8	20.5 $\pm$ 0.5
65	270.1 $\pm$ 5.5	264.7 $\pm$ 4.0	275.5 $\pm$ 5.1	23.3 $\pm$ 0.7	22.6 $\pm$ 0.6	23.5 $\pm$ 0.4

\*P<0.05, in comparing the following groups: normal--R and R--R+EE.



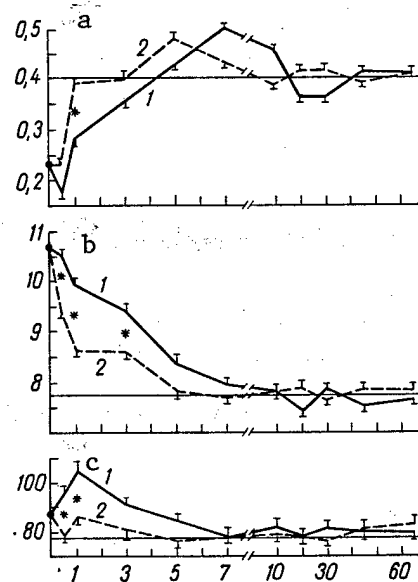
Effect of eleuterococcus on glycogen content and liver GPDH activity during recovery after 7-day hypokinesia. The beginning of each curve corresponds to level of tested parameters in rats after 7-day hypokinesia; the horizontal line shows the initial background for intact animals

X-axis, duration of recovery (days);  
y-axis, a--glycogen content (mg%),  
b--GPDH activity ( $\mu\text{mol NADP}\cdot\text{H}/\text{min}/\text{g}$   
tissue)

- 1) control \*P<0.05  
2) eleuterococcus

a sufficient degree of certainty four phases of recovery: intensification of stress reaction, compensation, supercompensation and normalization.

Discontinuation of hypokinesia was an additional stress factor. There was increase in functional activity of the adrenals after 12 h of recovery: their relative weight was 16% greater while cholesterol level was 22% lower than in animals on the last day of hypokinesia. The weight of the adrenals reached normal value within 3 days of recovery and held at this level throughout the 65-day observation period. After 12 h of recovery, liver glycogen content was 21% lower, HK 15% lower, GPDH 10% lower, while LDH was 10% higher than after 7-day hypokinesia. By the 3d day of the recovery period, there was insignificant activation of the adrenohypophyseal system: most of the parameters studied were close to normal; the period from the 1st to 3d days can be viewed as the compensation phase.



Effect of eleuterococcus on activity of HK, PEPCK and LDH of liver during recovery after 7-day hypokinesia.

Y-axis, a--HK ( $\mu\text{mol NADP}\cdot\text{H}/\text{min}/\text{g tissue}$ ), b--PEPCK ( $\text{mol PEP}/\text{min}/\text{mg protein}$ ), c--LDH ( $\mu\text{mol NAD}/\text{min}/\text{g tissue}$ ).

Other designations are the same as in Figure 1.

We observed the recovery process for 65 days. Considering the aggregate of changes in several biochemical parameters, we can single out with

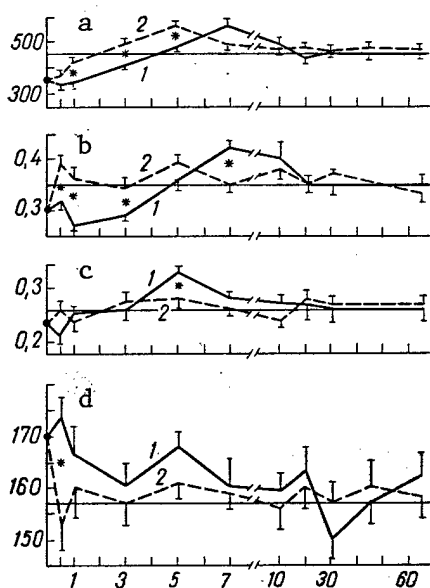


Figure 3.

Effect of eleuterococcus on carbohydrate metabolism in gastrocnemius during recovery after 7-day hypokinesia

Y-axis:

- a) glycogen content (mg%)
- b) HK ( $\mu\text{mol NADP}\cdot\text{H}/\text{min/g tissue}$ )
- c) GPDH ( $\mu\text{mol NADP}\cdot\text{H}/\text{min/g tissue}$ )
- d) LDH ( $\mu\text{mol NAD}/\text{min/g tissue}$ )

Other designations are the same as in Figure 1.

glycogen content of the liver and adrenal cholesterol content were 18 and 22% higher, respectively, i.e., the compensation phase was about two-thirds of its duration in animals who were not given this agent.

Supercompensation occurred differently in the two groups of rats. In the group given eleuterococcus it began sooner (on the 3d day) than in the control (5th day) and developed less intensively. Maximum elevation of cholesterol and glycogen levels, as well as maximum activity of HK, GPDH, constituted 121, 146, 125 and 151%, respectively, in the control group of animals with recovery and 108, 140, 115 and 142% in the group given eleuterococcus.

On approximately the 20th day of the recovery period, the animals' weight and tested biochemical parameters reached normal values with administration of eleuterococcus, whereas in the control group recovery occurred only by the 45th day.

The biochemical changes in the gastrocnemius presented the same direction as in the liver, but they were less marked (Figure 3).

Subsequently, from the 5th to 10th days, we observed increase in HK, GPDH activity and increase in liver glycogen content (125, 151 and 146%, respectively, on the 7th day), with elevation of adrenal cholesterol level (121% on the 10th day), i.e., this was the supercompensation phase.

In the period between the 30th and 65th days there was normalization of metabolic processes and the animals' general condition. The weight of rats in the control group reached the level in intact animals only after 45 days of recovery. The aftereffect of hypokinesia was quite protracted, and the recovery period was about 4 times longer than the exposure period.

Administration of eleuterococcus during the recovery period had a substantial effect on intensity of biochemical processes without altering their direction. Against the background of this agent, we did not observe the phase of intensification of the stress reaction; apparently it was much shorter in duration and less marked than in control animals.

With use of eleuterococcus, the activity of the tested enzymes reached normal within 1 day of the recovery period,

Evidently, eleuterococcus helps stabilize the activity of enzymes of carbohydrate metabolism and its speedy compensation, as a result of which we observe less marked supercompensation and faster (by about 2 times) return to the initial background (in intact animals).

Thus, the submitted results of our studies enable us to validate the desirability of using eleuterococcus in order to accelerate normalization of homeostasis during recovery following hypokinesia.

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EFFECT OF HYPOKINESIA ON AMINO ACID METABOLISM IN RATS ON DIETS DIFFERING IN CALCIUM AND PHOSPHORUS CONTENT

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 7 Jan 83) pp 58-60

[Article by T. F. Vlasova and Ye. B. Miroshnikova]

[English abstract from source] The effect of hypokinesia on amino acid metabolism was studied in rats kept on diets with different ratios of calcium and phosphorus. It was shown that excessive phosphorus in the diet led to a significant decrease of the amino acid pool, thus aggravating the hypokinetic effect.

[Text] It is known that hypokinesia elicits certain changes in parameters of amino acid metabolism in animals, and their severity depends on duration of hypokinesia [1-5]. Direct and indirect data have been accumulated to date, which indicate that there is decrease in intensity of synthesis of tissue proteins and increase in intensity of their degradation in hypokinetic animals [4]. For this reason, studies related to investigation of the amino acid pool are of definite interest, since protein synthesis occurs by including in biochemical processes its direct constituents--free amino acids. In view of the significance of the calcium and phosphorus proportion in the diet to their metabolism and existing correlation between phosphorus-calcium and amino acid metabolism, it is interesting to examine the levels of free amino acids in blood of hypokinetic animals against the background of diets containing different proportions of calcium and phosphorus. We found no data in the literature concerning the influence of such factors on amino acid metabolism.

#### Methods

The method of ion-exchange chromatography on a Liquimat III (Labotron, FRG) automatic analyzer was used to assay blood serum free amino acids in rats [6, 7]. At first, the tested blood serum samples were deproteinized with sulfo-salicylic acid [8]. The experimental conditions are described in the article of M. S. Belakovskiy et al. [9]. The animals were divided into groups: the first group received calcium and phosphorus in a ratio of 1:0.5 in their diet, the second 1:1, the third 1:2 and the fourth 1:3. They were submitted to hypokinesia for 30 days.

## Results and Discussion

Tables 1 and 2 list data on levels of free amino acids in rat blood serum under hypokinetic conditions as related to diets with different calcium:phosphorus ratios.

Table 1. Free amino acid content (mg%) in rat blood serum under hypokinetic conditions with different Ca:P ratio in the diet (first and second groups of animals)

AMINO ACIDS	Ca:P = 1:0.5 (first group)				Ca:P = 1.1 (second group)			
	CONTROL (n=4)	HYPOKINESIA (n=4)	P	DEVIATION FROM BASE DATA	CONTROL (n=4)	HYPOKINESIA (n=4)	P	DEVIATION FROM BASE DATA
ISOLEUCINE	1,29±0,17	1,32±0,24	>0,1	+0,03	1,82±0,20	2,30±0,20	>0,1	+0,48
LEUCINE	2,67±0,24	2,31±0,26	>0,1	-0,36	3,36±0,42	2,95±0,68	>0,1	-0,41
VALINE	1,70±0,17	3,13±0,34	<0,01	+2,13	2,60±0,22	2,30±0,60	>0,1	-0,30
THREONINE	4,4±0,46	3,72±0,61	>0,1	-0,68	5,42±2,24	3,60±2,44	>0,05	-1,82
SERINE	6,31±1,20	5,57±0,65	>0,1	-0,74	4,77±0,32	4,04±0,44	>0,1	-0,73
METHIONINE	1,00±0,07	1,13±0,20	>0,1	+0,13	1,11±0,08	1,42±0,10	<0,05	+0,31
TYROSINE	1,73±0,08	1,59±0,13	>0,1	+0,36	1,35±0,05	1,45±0,12	>0,1	+0,10
PHENYLALANINE	0,84±0,11	1,95±0,31	<0,02	+0,81	1,16±0,03	1,76±0,11	<0,001	+0,66
ASPARTIC ACID*	1,71±0,32	1,83±0,29	0	+0,12	2,01±0,28	1,82±0,35	>0,1	-0,19
GLUTAMIC ACID**	3,39±0,53	2,52±0,56	>0,1	-0,83	3,73±0,88	3,49±0,87	>0,1	-0,24
PROLINE	5,64±0,45	3,48±0,63	<0,05	-2,16	5,44±0,5	4,33±0,14	<0,05	-1,11
GLYCINE	1,72±0,24	2,24±0,53	>0,1	+0,52	2,64±0,53	3,43±0,38	>0,1	+0,79
ALANINE	3,68±0,53	4,32±0,79	>0,1	+0,64	4,95±0,22	5,13±0,40	>0,1	+0,18
LYSINE	17,79±1,64	15,06±2,43	>0,1	-2,73	18,42±0,62	14,97±1,60	>0,05	-3,45
HISTIDINE	2,17±0,21	1,63±0,24	>0,1	-0,44	2,22±0,52	2,64±0,32	>0,1	+0,42
ARGININE	2,95±0,24	3,30±0,87	>0,1	+0,35	2,29±0,10	3,57±0,60	>0,05	+1,28
SUM OF 16 AMINO ACIDS	59,0	56,7		-2,3	63,4	59,2		-4,2

Note: Here and in Table 2: \*With asparagine, \*\* With glutamine.

In the first group of animals there was a decrease in overall blood serum free amino acid content (2.3 mg% change in the experiment). The reduction of the amino acid pool occurred primarily due to decline of levels of proline ( $P<0.05$ ) and lysine, against a background of increase in concentrations of valine ( $P<0.01$ ) and phenylalanine ( $P<0.02$ ).

In the second group of animals, we also found a decline of the amino acid content of blood (4.2 mg% change during the experiment), with decrease in concentration of proline ( $P<0.05$ ) and a tendency toward decline of lysine ( $P<0.05$ ) and threonine ( $P>0.05$ ) levels. Conversely, there was an increase in phenylalanine ( $P<0.001$ ) and arginine ( $P<0.05$ ) content.



Table 2. Free amino acid content (mg%) in rat blood serum under hypokinetic conditions with different Ca:P ratio in the diet (third and fourth groups of animals)

AMINO ACID	Ca:P = 1.2 (third group)				Ca:P = 1.3 (fourth group)			
	CONTROL (n=4)	HYPOKIN. (n=4)	P	DEVIAT. FROM BASE DATA	CONTROL (n=4)	HYPOKIN. (n=4)	P	DEVIAT. FROM BASE DATA
ISOLEUCINE	1,76±0,30	1,79±0,29	>0,1	+0,03	1,95±0,14	1,87±0,21	>0,1	-0,08
LEUCINE	3,58±0,12	2,86±0,26	<0,05	-0,72	3,93±0,25	3,23±0,30	>0,1	-0,70
VALINE	1,99±0,17	4,18±0,19	<0,01	+2,19	2,54±0,29	2,58±0,26	>0,1	+0,04
THREONINE	5,88±0,66	5,87±0,65	>0,1	-0,01	6,21±0,42	4,22±0,24	<0,01	-1,99
SERINE	6,46±0,38	6,30±0,16	>0,1	-0,16	5,53±0,85	5,12±0,11	>0,1	-0,41
METHIONINE	1,20±0,12	1,27±0,04	>0,1	+0,07	1,59±0,19	1,53±0,18	>0,1	-0,06
TYROSINE	1,72±0,43	1,51±0,15	>0,1	-0,21	2,60±0,22	1,82±0,21	>0,1	-0,78
PHENYLALANINE	1,46±0,15	1,47±0,14	>0,1	+0,01	1,39±0,12	1,49±0,10	>0,1	+0,10
ASPARTIC ACID*	2,27±0,27	2,14±0,38	>0,1	-0,13	1,81±0,31	1,64±0,21	>0,1	-0,17
GLUTAMIC ACID**	3,68±0,34	4,24±0,39	>0,1	+0,56	3,60±0,32	4,26±0,34	>0,1	+0,66
PROLINE	3,83±0,80	3,13±0,59	>0,1	-0,70	6,59±0,62	4,54±0,08	<0,02	-2,05
GLYCINE	2,42±0,22	2,55±0,12	>0,1	+0,13	2,79±0,19	2,54±0,20	>0,1	-0,25
ALANINE	4,7±0,52	4,72±0,82	>0,1	+0,02	5,25±0,57	4,76±0,63	>0,1	-0,49
LYSINE	17,32±1,27	14,31±1,29	>0,1	-3,01	21,01±5,68	19,90±3,58	>0,1	-1,81
HISTIDINE	1,43±0,28	1,77±0,35	>0,1	+0,34	2,87±0,37	1,64±0,3	>0,05	-1,23
ARGININE	3,15±0,35	3,92±0,21	>0,1	+0,77	3,4±0,27	2,47±0,29	>0,05	-0,95
SUM OF 16 AMINO ACIDS	62,8	61,31		-1,49	73,06	63,61		-9,45

In the third group of animals (see Table 2) total free amino acid content dropped to 61.3 mg%, as compared to the control--62.8 mg% (1.49 mg% deviation during the experiment). This decline was attributable to insignificant decline of leucine level ( $P<0.05$ ) against a background of increase in valine concentration ( $P<0.01$ ).

Finally, in the fourth group of animals, the free amino acid pool diminished to the greatest extent under the influence of experimental conditions (9.5 mg% change during experiment). In this case, there was reliable drop of threonine ( $P<0.01$ ) and proline ( $P<0.02$ ) levels, against the background of a tendency toward decrease in concentrations of histidine and arginine.

The data obtained in these experiments indicate that there was a decrease in free amino acid content of rat blood serum in all four groups of animals submitted to hypokinesia for 30 days. The extent of reduction of the amino acid pool depended on the quantitative Ca:P ratio in the diet. The amino acid composition in blood serum changed the most in the fourth group of rats (Ca:P = 1:3). We know from the literature that hypokinesia reduces the amino acid pool of blood, which is related to depression of protein synthesis in tissues [4]. Our studies indicate that excessive phosphorus intake causes a decrease in amino acids of the blood in hypokinetic animals (4th group). The changes were less marked in the 1st-3d groups of animals, and they were related to the Ca:P ratio in their diet.

The results obtained in the course of this study revealed that excessive phosphorus intake leads to significant decline of amino acid pool of rat blood, thereby aggravating the effect of hypokinesia.

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DEMONSTRATION OF GAS BUBBLES IN CANINE PULMONARY ARTERY AND AORTA BY  
MEANS OF ULTRASONIC ECHOGRAPHY WITH INTRAVENOUS AIR INFUSION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17,  
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[Article by V. P. Nikolayev, V. P. Katuntsev, R. T. Kazakova, R. I. Finogenova,  
K. S. Yurova, T. D. Doronina, A. D. Mansfel'd, P. K. Chichagov and  
A. M. Reyman]

[English abstract from source] The transducer and receiving amplifier of a standard ultrasonic echocardiograph were modified to develop a device for detecting unmasked echocardiographic images of gas bubbles in blood vessels. This device was employed to detect gas bubbles passing from the venous to the arterial bed via lungs in anesthetized and thoracotomized dogs during air intravenous infusion. Gas bubbles entered the aorta when the dose of infused air was 12-15 ml. It is postulated that gas bubbles formed in the animal and human body during decompression may pass from the venous into the arterial bed not only through shunts but also through lung capillaries.

[Text] Of all the means of detecting gas bubbles (GB) in man and animals developed to date, the most effective are ultrasonic devices and, among them, instruments based on use of the Doppler effect have become particularly popular [1-5]. Such instruments, which usually operate in the mode of continuous emission of ultrasound, permit demonstration only of relatively large GB (over 50  $\mu$ m in diameter) moving together with blood. Methods of demonstrating GB with use of echographic apparatus, which probes different parts of the body with pulsed ultrasound, are less used. Equipment of this type does, in theory, permit detection of both moving and stationary GB in the body. And, unlike the dopplerian instruments, echographic apparatus detects GB of appreciably smaller size [6, 7] and shows their exact location. However, when receiving echo signals at the sounding frequency, the image of GB on echograms is obscured by the image of structurally heterogeneous tissues around them. For this reason, identification of GB on echograms by traditional methods [6, 7] is often questioned.

Our objective here was to check the possibility of obtaining unobscured GB images of GB in blood vessels by means of modified echographic equipment and of recording with this equipment the passage of GB from the venous system into the arterial one through the lungs of animals during intravenous injection of air.

## Methods

We performed a midline thoracotomy on 8 mongrel dogs of both sexes weighing 9.2-17.6 kg under nembutal (70 mg/kg) anesthesia, then isolated the aortic arch and pulmonary trunk, which branches into the right and left pulmonary arteries. The animals were immobilized in supine position, and artificial ventilation of the lungs was performed using a Lada-TM apparatus, at a frequency of 8-10 cycles/min. We assessed efficacy of ventilation according to CO<sub>2</sub> concentration in exhaled air, which we measured in each respiratory cycle with an LB-2 gas analyzer of the Beckman Firm and recorded in the form of capnograms using an N-338 automatic recorder. Periodically, we took blood samples from the femoral artery, through a catheter, and for the next 2-3 min determined pO<sub>2</sub>, pCO<sub>2</sub> tension and pH using AVL-940 and ABL-2 apparatus. Air was injected at the rate of 5 ml/min using a syringe, through a polyethylene catheter, with inside diameter of 1 mm, inserted in the femoral vein. At first, air was injected for 2 min, then in each subsequent cycle the injection was extended by 2 min, as compared to the preceding time. Each new cycle of air injection was started after relative normalization of the capnogram and parameters of gas composition of arterial blood. Air was injected once at the rate of 10 ml/min for 2 min to 2 animals.

For demonstration of GB in the pulmonary trunk and arch of the aorta, we used our modification of the UZKAR-3 ultrasonic echocardiograph, which has a carrier frequency of 2.64 MHz, probing pulses of 2  $\mu$ s and recurrence frequency of 1.2 kHz. We added into the circuit of the standard instrument a system for temporary automatic regulation of amplification (TARA), which enables us to lower the set sensitivity of the receiver during delivery to it of echo signals from the nearest probing zone. In addition, to improve locating conditions for bubbles in this zone, we specially developed a sensor with spatially separated transmitting and receiving piezoconverters, which were submerged in the sensor and placed at an angle to one another so that their geometric axes would intersect in the immediate vicinity of the surface of the sensor. The location on echograms of the surface of such a sensor was identified from an echogram showing a metal plate coming toward and away from the sensor placed in water.

In order to assure solid ultrasonic contact of the sensor with the probed parts of vessels, its surface was swabbed with sound-conducting paste. During observation and photography of echograms in probing accessible parts of the pulmonary trunk and aortic arch, the sensor was fixed alternately on their surface by the researcher, manually. The power of emitted ultrasound, sensitivity the echo-signal receiver, cut-off of the background of amplifier receiver and TARA level in the modified UZKAR-3 instrument were so selected as to have no echo signals from the nearest zone of probed regions of the cardiovascular system on the echogram prior to injection of air into the vessel. The echogram pattern on the oscillograph screen was periodically photographed with a Zenith-E camera. The frames thus obtained represent separate fragments of echograms that are viewed continuously on the screen of another oscilloscope.

## Results and Discussion

Figure 1a illustrates a fragment of an echogram obtained when probing the pulmonary trunk of one of the animals before intravenous injection of air. The distance between two adjacent markers vertically corresponds to a depth of 1 cm probing and horizontally to an interval of 0.5 s. The location of the sensor's surface on the echogram is marked by the GB level. The pulmonary trunk about 1 cm in diameter, is right under the surface of the sensor, but because the reflected ultrasonic signal is suppressed in the nearest probing zone, its structure is invisible. The thick oscillating lines in the far zone of probing, 3 and 5 cm away from the surface of the sensor are echo signals from cardiac structures underneath the pulmonary trunk.

The air injected in the femoral vein inevitably reaches the right heart and then the pulmonary trunk in the form of different sized bubbles, but it is a matter of chance to be able to take a photo of the moment of appearance of the first bubble in the probed field. Figure 1b illustrates a fragment of an echogram during probing of the pulmonary trunk a few seconds after gas bubbles have entered it. Because of absorption and scatter of bubbles [?] due to energy of the probing ultrasound, the previously visible structure of the heart 3 cm from the sensor becomes invisible. As air injection continues, the amount of GB in the pulmonary trunk increases even more, and for this reason, as can be seen in Figure 1c, absorption and scatter of ultrasound emitted ultrasound become so strong that there is disappearance of even the most contrasted structure of the heart at a depth of 5 cm. At first glance, it would seem that the echo signals that are typical for bubbles also come from the space beneath the pulmonary trunk. However, these pseudo-signals are secondary images of GB located in the lumen of the pulmonary trunk. They appear as a result of re-reflection of primary echo signals from the sensor's surface and other GB.

Figure 2 illustrates fragments of echograms when probing the aortic arch of the same animal. It is about 1.5 cm in diameter. Before air injection and during brief injection of air, only structures of the heart situated under the aorta are visible on the echogram (see Figure 2a). In the frame illustrated in Figure 2b, we were able, by chance, to record the moment when GB began to enter the aorta. With increase in quantity of GB passing through it, underlying structures of the heart show less contrast (see Figure 2c). After discontinuing air injection into the venous bed, massive passage of GB into the aorta stopped and, thereafter, as long as pulmonary embolization persisted, only isolated GB penetrated into it sporadically (the two bright points in Figure 2d, 1.0 and 0.6 cm from the surface of the sensor).

The echograms illustrated in Figures 1 and 2 indicate that we can set the UZKAR-3 instrument that we modified for operating so that the image of tissular structures in the nearest probing zone is eliminated. This is obtained by lowering sensitivity of the receiver for near echo signals by means of appropriate adjustment of TARA. At the same time, retention of set sensitivity of the receiver for far echo signals makes it possible to keep the image of tissue structures in the far zone of probing. One can determine that the chosen site and direction of probing have not changes in the course of the experiment from the location and distinctive features of this reference image.

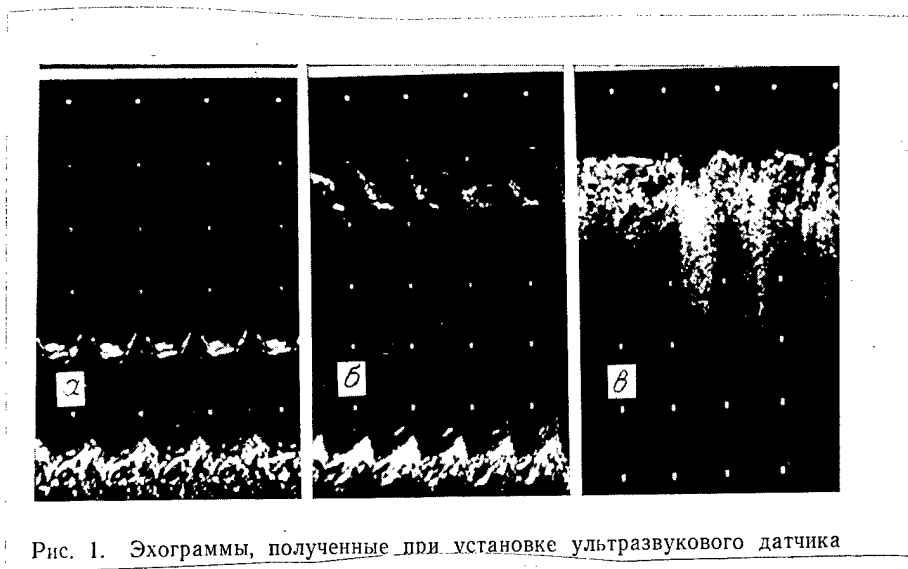


Рис. 1. Эхограммы, полученные при установке ультразвукового датчика на поверхность легочного ствола собаки

ПД [not evident on photos] here and in Figure 2--location of surface of sensor

- a) before
- б) 20 s after
- в) 1 min after start of intravenous injection of air

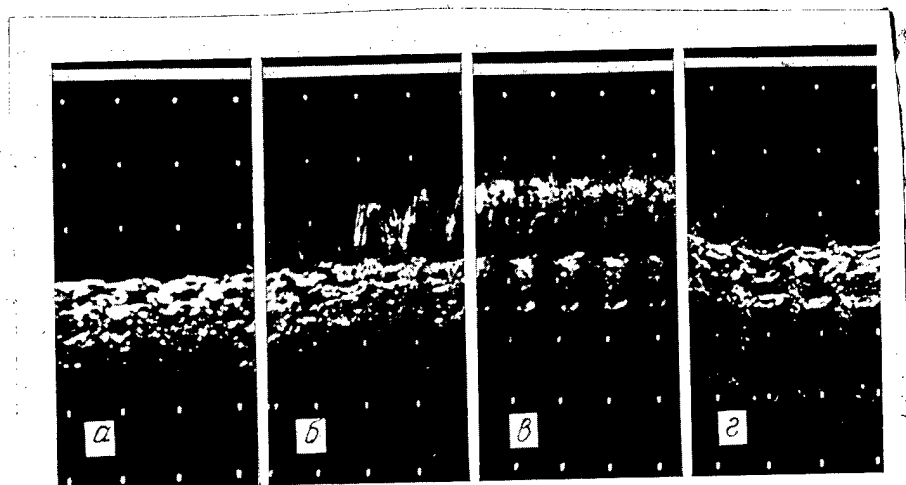


Рис. 2. Эхограммы, полученные при установке ультразвукового датчика на поверхность дуги аорты собаки

Figure 2. Echograms obtained with ultrasonic sensor placed on surface of dog's aortic arch

- a) before
- б) 2 min 30 s after
- в) 3 min 20 s after start
- г) 20 s after finishing 4-min cycle of intravenous infusion of air

The possibility of obtaining unobscured echographic images of GB in the near probing zone is due to the fact that, as compared to tissues, they are more effective reflectors of ultrasound. The amplitude of echo signals from GB is proportionate to their radius, and for GB, the size of which exceeds a certain level it is above the threshold of receiver sensitivity set by the TARA. Determination of optimum performance characteristics of the equipment (energy of emitted ultrasound, general amplification of receiver, adjustment of TARA), at which it is possible to obtain unshaded images of the smallest GB at different probing depths, as well as estimation of such sizes, require special investigation. In solving this problem, one must take into consideration the substantial increase in amplitude of echo signals from small bubbles, the size of which is close to resonance. For the ultrasound emitted by the UZKAR-3 instrument, with carrier frequency of 2.64 MHz, GB with a radius of 1.2  $\mu\text{m}$  are resonant.

In spite of the intermittent nature of emission of ultrasound, the equipment we used can record not only the prolonged, but short-term presence of GB that it detects in the probed parts of vessels. Indeed, since the width of the ultrasound beam emitted by the sensor is 1 cm, at a recurrence frequency of 1.2 kHz for probing pulses, only GB that travel together with blood at velocities in excess of 12 m/s could elude such scanning. However, even in the aorta, the linear velocity of blood flow is at least one-twentieth as slow as the above rate.

In our experiments, with each cycle of intravenous injection of air, the animals presented a significant decline of  $pO_2$  and elevation of  $pCO_2$  in arterial blood, which was indicative of drastic reduction of efficiency of gas exchange in the lungs. The magnitude of change in these parameters of gas composition of blood was related to the dosage of air. Penetration of GB into the aorta usually occurred within 2-3 min of the second and subsequent cycles of air injection at the rate of 5 ml/min. In 2 animals, which were given a single air injection at the rate of 10 ml/min, GB appeared in the aorta about 1.5 min after the start of this procedure. Thus, at both velocities of air infusion, appearance in the aorta of GB that are detectable by our equipment occurred at the time when the dosage of injected air reached 12-15 ml. However, it is quite possible that passage into the aorta of GB that cannot be detected by our equipment in the short-range zone (small GB, from which the echo signals are smaller in amplitude than the receiver sensitivity threshold set by TARA) began with a smaller dose of air, i.e., with less embolization of the lungs.

With reference to the causes of penetration of GB from the venous system into the arterial one, it should be noted first of all that physiologists have formed a universally recognized idea about the lungs as a filter that does not allow GB to pass through it into the left heart. The action of the lungs as a barrier to GB is attributable to the fact that, because of presence of force of surface tension, propulsion of large (as compared to erythrocytes) GB through the capillaries would occur only with pressure elevation in pulmonary arteries to the unrealistically high level of 150 mm Hg [8, 9]. Gas diffuses into the alveolar space from the capillaries blocked by bubbles, and it is driven outside with exhaled air. At the same time, fine GB, the size of which is less than the diameter of an erythrocyte,

could, it would appear, pass through the pulmonary capillaries without difficulty. However, according to mathematical models [10, 11] that describe evolution of GB in physical and biological media, their life span is quite limited. Thus, in air-saturated water, spherical bubbles 10  $\mu\text{m}$  in diameter (which is somewhat larger than the diameter of a capillary) are resorbed in about 1 s, i.e., in the time that blood travels through pulmonary capillaries.

Nevertheless, some of the venous GB are still capable of penetrating into the arterial system, not only in thoracotomized animals as in our experiments, but in intact ones, as well as in man. This is indicated, in particular, by studies [1-3] conducted on sheep and pigs with ultrasonic sensors implanted on the surface of the vena cava and aorta. In such animals, appearance of GB in the aorta was demonstrated with both intravenous injection of air [1] and decompression from high to ground pressure [2, 3].

It is quite likely that, with embolization of the lungs, penetration of GB into the aorta is facilitated as a result of dilatation of the lumen of functional and opening of previously nonfunctional pulmonary shunts. However, GB can pass from the venous to the arterial bed, not only through anatomical pulmonary shunts and unfused foramen ovale of the heart, but apparently also through the pulmonary capillaries. The possibility of passage of GB through pulmonary capillaries is due to the following causes. In small-caliber vessels, moving GB are surrounded by a limited amount of blood and, for this reason, as noted by V. P. Nikolayev [12], their resorption, which elicits local oversaturation of blood with gases, could be entirely arrested or, at least, occur more slowly than in large vessels. The process of GB resorption in blood is also retarded if they have membranes of surfactant substances, which have a low coefficient of surface tension. In the case of a slower rate of resorption, the fine GB have time to pass through the pulmonary capillaries and turn out to be in the pulmonary veins. Segments of the lungs that are partially or entirely unventilated create particularly favorable conditions for passage of GB in capillaries. Small GB coming simultaneously from different capillaries can merge into larger ones in pulmonary veins and, consequently, into longer lasting ones. Moreover, the relatively large GB, when they have surfactant membranes, can apparently be propelled through capillaries, even when there is insignificant elevation of pressure in pulmonary arteries [9]. For example, in the experiments of Spencer and Oyama [3], penetration into the aorta of GB that were detectable by ultrasonic dopplerian equipment began when systolic pressure in the pulmonary arteries reached 35 mm Hg.

The studies of I. A. Sapov et al. [4] show that, with virtually any decompression, that is beneficial to man and animals, from elevated pressure in the venous parts of their circulatory system, there is formation of GB whose movement toward the heart and lungs is distinctly demonstrable by ultrasonic dopplerian equipment. We could expect that the same phenomenon occurs with decompression from ground-based pressure to low pressure. Penetration of venous GB into the arterial bed is fraught with embolization of vital organs and, as a result, development of serious forms of caisson's disease. This sometimes happens even without the usually occurring prior manifestation of mild forms of this disease. However, the technical capabilities of existing GB indicators are not sufficient for operational prediction of dangerous penetration of GB into the arterial system. The



results of our studies convince us that one of the means of solving this problem is to develop equipment, with which one could measure in a non-invasive way the overall volume of GB, both those entering the lungs with the flow of venous blood and passing through them into the arterial system per unit time.

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PHYSIOLOGICAL AND ECOLOGICAL CHARACTERISTICS OF THE WATER FERN, AZOLLA PINNATA, AND PROSPECTS OF USING IT IN BIOLOGICAL LIFE-SUPPORT SYSTEMS FOR MAN

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian, Vol 17, No 5, Sep-Oct 83 (manuscript received 7 Jan 83) pp 66-69

[Article by Ye. Ya. Shepelev, Nguen Thyok, G. I. Meleshko, A. A. Antonyan, T. B. Galkina and V. P. Naydina (USSR and Socialist Republic of Vietnam)]

[English abstract from source] The principal physiological and ecological characteristics of *Azolla pinnata* were investigated in order to determine its potential use in biological life support systems. Plant requirements for biogenic elements were specified in order to develop balanced nutrient mixtures for continuous cultivation. Data on the growth and development, photosynthetic and nitrogen fixation rate, and biochemical composition of the plant were obtained for optimal cultivation conditions. The plant biomass contains large quantities of carotenoids and sulfur-containing amino acids, which are deficient in unicellular algae. This makes *Azolla* an attractive source of the above compounds for biological life support systems and other applications.

[Text] During the mission of the joint Soviet-Vietnamese crew aboard the Salyut-6--Soyuz-37 station, a study was made of the effect of weightlessness on the water fern, *Azolla* (*Azolla pinnata*) furnished by Vietnamese scientists [1]. Upon further study of this plant, it was found of interest as well from the standpoint of use in closed ecological systems in order to fix atmospheric nitrogen with symbiotic algae. This property can be contrasted to processes of lysis of nitrogen, which occurs in a system of biological and physicochemical mineralization of products of human vital functions.

The *Azolla* is widespread in countries of Southeast Asia; it lives on the surface of water in stagnant reservoirs or those with minimal flow. The sporophyte of the *Azolla* is a branched floating rhizome that is densely covered with leaves. The blue-green microscopic alga, *Anabaena*, lives in symbiosis with this fern; it grows and multiplies in its air chambers and is capable of binding atmospheric nitrogen, converting it to the ammonia form that can be assimilated by plants. For this reason, when it multiplies in rice paddies, *Azolla* is instrumental in improving soil fertility without use of nitrogen fertilizers, and it is very important to the national economy.

There is a vast literature dealing with Azolla, which pertains primarily to studies of correlations in the Azolla-Anabaena symbiosis [2-5] and nitrogen metabolism in symbiosis [6, 7]. There is a book [8] that deals with traditional use of Azolla as nitrogen fertilizer in growing rice in Vietnam, India, China and Indonesia [8]. We found no information in the literature concerning physiological and ecological characteristics of Azolla, or conditions for growing it in the laboratory.

Our objective here was to investigate the main physiological and ecological characteristics of Azolla cultivated in the laboratory in order to assess the possibility of using it in human BLSS [biological life-support systems] and to obtain data to calculate its parameters for use in specific BLSS models.

## Methods

The plants were raised in natural light (12-h photoperiod) and the experiment lasted 15-20 days. In the course of the tests, we studied the concentration of biogenic elements in the medium and their levels in biomass, plant productivity, rate of nitrogen fixing and photosynthesis, composition of biomass and pigments, morphological structure of plants.

First of all, we studied the conditions of mineral nutrition of the plants in order to initiate intensive cultivation of Azolla and study its basic characteristics relevant to human BLSS.

The nutrient media used to raise Azolla contain no nitrogen. Nitrogen nutrition was provided by atmospheric nitrogen fixed by blue-green algae in symbiosis with the plant. At the first stages, we used Olsen's medium, which was recommended by the Institute of Biology, Socialist Republic of Vietnam (SRV). Its formula is listed in Table 1. The very first tests with

Table 1.  
Nutrient media for growing Azolla

CHEMI CAL	OLSEN MEDIUM	OLSEN MEDIUM MODIFIED AT I BMP	MEDIUM BALANCED AT I BMP FOR ESSENTIAL ELEMENTS MG/G DRY SUBSTANCE
	MG / L		
KCl	109,0	109,0	115,0
CaCl <sub>2</sub>	113,0	113,0	8,0
KH <sub>2</sub> PO <sub>4</sub>	23,0	—	—
K <sub>2</sub> HPO <sub>4</sub>	—	115,0	130,0
MgSO <sub>4</sub> ·7H <sub>2</sub> O	101,0	101,0	41,2
MnSO <sub>4</sub> ·H <sub>2</sub> O	0,3	0,3	0,3
H <sub>3</sub> BO <sub>3</sub>	0,4	0,4	0,4
ZnSO <sub>4</sub> ·7H <sub>2</sub> O	0,2	0,2	0,2
CuSO <sub>4</sub> ·5H <sub>2</sub> O	0,1	0,1	0,1
FeC <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ·H <sub>2</sub> O	10,0	10,0	10,0
FeSO <sub>4</sub> ·7H <sub>2</sub> O	—	6,0	6,0
EDTA	—	7,4	7,4
pH	5,6	6,5	6,8

Key: IBMP) Institute of  
Biomedical Problems

this medium revealed that it is not suitable for intensive cultivation of the plants. This was due to the low concentration of phosphorus in the medium, as well as poor solubility of iron salts, which led to rapid depletion of these biogenic elements in the medium. For this reason, we modified the recommended nutrient medium. The modification consisted of increasing the phosphorus content by 5 times and adding salts of iron sulfate with Trilon. We studied the principal characteristics of Azolla on the above medium.

## Results and Discussion

First of all, we had to determine whether the composition of the nutrient medium conformed to Azolla requirements in biogenic elements, which we studied according to accumulation of elements in biomass. This characteristic is

necessary to plan the nutrient media and corrective solutions, as well as assure balanced flow of nutrients during continuous cultivation in a system with closed circulation of matter. Table 2 lists the amounts of biogenic elements in biomass of *Azolla* raised at different temperatures. With regard to its chemical composition, this fern is characterized by a high potassium and phosphorus content. Unlike other higher plants, it contains a considerable amount of nitrogen, 35-36 mg/g dry weight. The amount of biogenic elements contained in *Azolla* was unrelated to temperature (within the tested range).

Table 2. Biogenic element content (mg/g dry matter) in *Azolla* cells at different temperatures

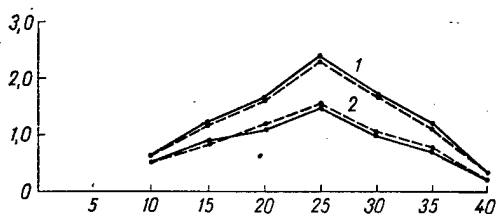
Variant of experiment	Parameter	Biogenic elements						
		N	P	S	K	Mg	Ca	Fe
18-20 °C	$\bar{x} \pm S$	35,5 $\pm$ 2,7	17,6 $\pm$ 1,3	4,8 $\pm$ 0,5	60,0 $\pm$ 5,0	3,8 $\pm$ 1,0	2,8 $\pm$ 0,4	2,1 $\pm$ 0,2
	%V	7,5	7,3	10,0	8,0	25,9	14,0	9,5
32-35 °C	$\bar{x} \pm S$	36,6 $\pm$ 2,8	15,6 $\pm$ 1,1	4,0 $\pm$ 0,5	55,3 $\pm$ 3,8	3,5 $\pm$ 1,0	2,5 $\pm$ 0,3	1,9 $\pm$ 0,2
	%V	7,8	7,0	12,5	11,0	28,5	12,0	10,0

This comparison enabled us to determine that the recommended media were prepared without considering plant biogenic element requirements. For example, while there was a consistency between phosphorus content in the biomass and medium, we found that its magnesium and potassium levels exceed plant requirements by 8.2 and 3.3 times, respectively, there was 10 times more sulfur and almost 50 times more calcium than required.

On the basis of these data, we developed a medium that was balanced in the main elements (see Table 1), which enables us to make up the loss of elements during continuous cultivation of plants in accordance with their removal by the plants and, in the case of accumulative cultivation, to calculate the composition of medium and possible harvest per liter of nutrient solution with optimum utilization of mineral salts.

*Azolla* has a rather high rate of photosynthesis, in spite of the fact that it is a shade-loving plant. Light saturation of photosynthesis is observed at illumination that does not exceed 28 klux. Plants can transfer a high intensity of illumination (up to 70 klux) when exposed to it for a brief time. At low light intensity [10-12 klux), the rate of photosynthesis by *Azolla*, as measured from uptake of carbon dioxide, constituted about 10  $\mu\text{g}/\text{m}^2/\text{day}$ , which is about one-half the rate of photosynthesis in the most productive strains of *Chlorella* under identical cultivating conditions. Biomass doubled in 2-2.5 days.

Photosynthesis of *Azolla* is associated with fixing of atmospheric nitrogen by concomitant blue-green algae. These processes are interrelated. The Figure illustrates the changes in photosynthesis and nitrogen fixation at different temperatures. Maximum rate of these processes was observed at 25°C, which is optimum for growth and development of ferns.



Rate of photosynthesis (1) and nitrogen fixation (2) in Azolla as a function of temperature  
X-axis, temperature, °C;  
y-axis, nitrogen fixation (mmol ethylene/g/h) and rate of photosynthesis (mmol O<sub>2</sub>/g/h)

Azolla biomass is characterized by a high ash content, up to 9% dry weight, which is due to the high potassium content of cells. This fern differs from most higher plants in that it also has a high nitrogen content, 35-36 mg/g dry weight, which is represented mainly (up to 90%) by the protein fraction. Thus, Azolla contains 22-23% protein by dry weight, and its level does not depend on cultivation temperature (Table 3).

Examination of amino acid composition of Azolla revealed that the protein contains the basic assortment of amino acids inherent in plants. The total amount of amino acids at the two tested

cultivation temperatures constituted 22-25% of the biomass dry weight. Of this amount, 10-11% is referable to essential amino acids. A relatively large amount of amino acids referable to the metabolic pool--aspartic and glutamic acids--was found in the protein, and they constituted 9.6-13.6% of the total sum of amino acids, regardless of temperature. Azolla is considerably inferior to unicellular algae and appreciably superior to most higher plants in quantity and composition of protein amino acids. Azolla biomass is rich in carbohydrates, the amount of which is in the range of 35-39% (see Table 3). The carbohydrates consist essentially of those that are readily assimilated--sugar and starch. The share of starch is about 65% of total carbohydrates and monosaccharides constitute 20%. In spite of the presence of a considerable leaf surface and rhizoids, there was an insignificant amount of cellulose in Azolla biomass, constituting only 2-3% dry matter. Total carbohydrate content of Azolla biomass and its composition were unrelated to temperature at which the plants were cultivated.

Table 3.  
Biochemical composition of Azolla raised at different temperatures (% dry matter)

Temp. °C	Parameter	Protein	Lipids	Carbohydrate			Ash
				total	starch	mono-sacch.	
18-20	x	22,2	11,3	34,7	21,0	7,1	12,8
	±	2,9	1,3	4,0	2,6	1,0	1,5
	%	13,0	11,5	11,5	12,4	15,5	11,7
32-35	x	23,0	10,5	37,2	23,4	6,3	11,2
	±	2,7	1,8	2,9	2,6	0,9	0,6
	%	12,0	17,	7,8	11,1	14,3	5,3

Note: Number of readings--5.

Table 4.  
Fatty acid composition of Azolla lipids (% of total)

Acid	Fatty acid code	Temp.	
		18-20 °C	32-35 °C
Myristic	14:0	1,4	1,9
Palmitic	16:0	45,1	50,2
Palmitoleic	16:1	2,2	3,7
Stearic	18:0	7,0	4,0
Oleic	18:1	14,0	13,9
Linolic	18:2	15,8	14,3
Octadecatetra-enoic	18:4	14,3	11,8

Azolla lipids constitute 10-11% dry matter. They included fractions of phospholipids, free fatty acids, monoglycerides, diglycerides, triglycerides, as well as stearates. In all, we found 7 types of fatty acids with 14-20 atoms of carbon. More than half is referable to palmitic acid (Table 4). It is of great interest that the lipids of Azolla include octadecatetraenoic acid (18:4), which is very seldom encountered among the lipids of both higher and lower plants. According to data in the literature, this acid is contained in heterocysts of some blue-green algae, most often in *Oscillatoria*. The hypothesis has been expounded that there is a possible link between it and the nitrogen-fixing process. The presence of this compound in Azolla lipids is apparently related to the presence of *Anabaena*, which lives, as we know, in symbiosis with the fern under study. The qualitative composition of lipids, fatty acids and their proportion are subject to changes, depending on the temperature at which these plants are cultivated. At lower temperatures, there is an increase in relative share of unsaturated fatty acids, as a result of which there is also a change in ratio between unsaturated and saturated fatty acids, apparently due to the protective reaction of Azolla to low temperatures.

Pigments were found in the photosynthetic system of Azolla: chlorophylls a and b, carotene, lutein and violaxanthin, the total amount of which ranged from 4.0 to 5.0 mg/g dry substance, depending on the temperature. Chlorophylls a and b constituted more than 80% of all pigments. The ratio of chlorophyll content to carotenoids, as well as of chlorophyll a to chlorophyll b was close to those found in higher plants and it increased at higher temperature. It should be noted that Azolla contained a high level of carotenoids, as compared to certain other types of algae that we studied, which is indicative of the value of using this plant as a feed supplement.

These studies enabled us to obtain, for the first time, the complex characteristics of Azolla and assess the possibility of using it as part of BLSS for man. When this plant is included in the system, unlike other plants, photosynthetic output of oxygen would be associated with binding of atmospheric nitrogen, and this process may be mandatory in the system in order to compensate for dinitrification processes, which are not always controllable, in microbiological decomposition of nitrogenous substances. In addition, the system would be provided with additional new biomass that has a rather favorable composition. This biomass could be used entirely in the feed allowance of animals. Thus, as part of a life-support system for man, Azolla is capable of performing several combined functions. Preliminary studies of this fern in weightlessness failed to demonstrate any restrictions whatsoever to its use in spaceflights.

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PREDICTION OF VOMITING IN DOGS EXPOSED TO RADIATION WITH SHIELDING OF MIDABDOMEN

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 30 Sep 82) pp 70-72

[Article by T. F. Osokina, B. L. Razgovorov and B. I. Davydov]

[English abstract from source] This paper presents data on vomiting as a primary dose-dependent reaction of dogs to irradiation. It is shown that vomiting can be predicted with reference to the average absorbed dose in the abdominal area, provided the animal is irradiated in a lethal dose and the area is shielded. It is emphasized that calculated and experimental data are in good agreement.

[Text] It has been reported that the probability of symptoms of a primary radiation reaction and severity of its manifestations is considerably smaller in the case of nonuniform irradiation than total-body uniform irradiation [1-3]. In the case of nonuniform irradiation, which involves shielding of some parts of the body, the strongest attenuation of the primary reaction, including frequency and intensity of vomiting, is demonstrable in dogs, cats and monkeys when the abdominal region is shielded. Some researchers believe that the primary reaction is related only to the dosage of radiation to specific organs or tissues responsible for manifestation of this reaction [4-7].

An effort was made here to predict the probability of vomiting during the primary reaction of dogs under different conditions of abdominal shielding, on the basis of median absorbed dose ( $D_m$ ) to this region, similarly to what we had done previously in predicting survival of rats [8].

Methods

It can be considered that the contribution to effective radiation dose  $D_e$ , which elicits clinical manifestations of a primary reaction, will depend essentially on effective radiation dose to the abdominal region  $D'_e$ , i.e.,  $D'_e$ ,  $D_e$  and  $P \sim f(D'_e)$ , where  $P$  is probability of appearance of a primary reaction.



As in the study mentioned above, we assume that, with lethal doses of radiation, radiation damage depends primarily on mean absorbed dose in the abdominal region, i.e., we assume that  $D_e = D_m$ . In order to estimate  $D_m$ , we consider the abdominal region as a sphere, the center of which is on the longitudinal axis of the body. The shielded area is a part of the spherical layer, the height of which equals the width of the shield. In this case, when the shielding is placed on any level in the abdominal region, the center of the sphere is always midway on the height of the spherical layer cut off by the shield, i.e., the shield can increase in width only symmetrically in relation to the large circle of the sphere that is perpendicular to the body's longitudinal axis.

The probability of vomiting in the primary reaction as a function of radiation dose with shielding of the abdominal region can be written down in general form as follows [8]:

$$P = [\log (D - DV + dV) - a] : b \quad (1)$$

where  $P$  is frequency of symptom in probit units,  $D$  is exposure dose,  $V$  is volume of shielded tissues,  $d$  is residual dose under shield,  $a$  and  $b$  are coefficients of regression equation of the dose-effect curve (for dogs) in the case of total-body irradiation.

We conducted experiments on 138 dogs (average weight 10-12 kg) in order to determine coefficients  $a$  and  $b$  in the regression equation and for experimental evaluation of efficacy of shielding the midabdomen with different doses of radiation. The animals were exposed to unilateral  $\gamma$ -radiation from a "Khizotron" unit with a  $^{60}\text{Co}$  charge at a dose rate in air of 5-6.5 R/min.\* The dogs were placed in the zone of uniform irradiation 1.5 m from the source, in a special box-stand. Dosimetric studies were made using a VA-1-18 dosimeter with overall margin of error not exceeding 5%.

We used lead blocks made of sheets to shield the abdomen, and they provided for attenuation of dosage of 1/2, 1/3, 1/5 and 1/10. The width of the shields was in the range of 6-8 cm depending on the weight of the dog (in making calculations on a model, we used 7 cm as the average shield width). The methods for immobilizing, shielding and irradiating the animals are described in greater detail by B. L. Razgovorov and N. I. Konnova [9]. We assessed the effects in our experiments chiefly by determining the frequency and severity of vomiting.

### Results and Discussion

We demonstrated a distinct dependence of frequency of vomiting on radiation dose in our experimental tests on 72 dogs exposed to radiation in doses of 300-800 R. The coefficients in the regression equation of the dose-effect curve for dogs submitted to total-body radiation were:  $a = -11.72$  and  $b = 6.39$ . We determined, on the basis of special morphological studies that we conducted on frozen dog carcasses, that the mass of all organs and

\*1 R =  $2.58 \cdot 10^{-4}$  C/kg (in SI units).

tissues protected by this shield in the central abdomen constituted a mean of 10-12% of the animal's total weight, while the mass of only protected parenchymatous organs constituted a mean of 5.6% (6.3-4.9). We found that the following organs were protected: spleen (entirely or most of it), right kidney and half or the anterior two-thirds of the left kidney, both adrenals, a considerable part of the pancreas, about half the body of the stomach, about 70% of the intestine and certain other organs.

Predicted and experimental data on occurrence of vomiting in dogs after exposure to  $\gamma$ -radiation in lethal doses with shielding of the midabdomen

D, P	d, P	V <sub>sh</sub> /V <sub>sph</sub> , relative units		N	Probability of vomiting, %			Δ <sub>1</sub>	Δ <sub>2</sub>
		1	2		Exper- iment	forecast			
						1	2		
500	250	0,661	0,664	17	18	28	29	—10	—11
600	300	0,661	0,664	10	20	47	48,2	—27	—28,2
800	400	0,661	0,664	7	100	76,4	77,6	+23,6	+22,4
800	270	0,661	0,664	12	33	59,4	62	—26,4	—29
800	160	0,661	0,664	8	25	40	43	—15	—18
800	80	0,661	0,664	12	25	25	28	0	—3

Key:  $\Delta_1$ ) difference (%) between experiment and predicted effect according to formula for a shield 7 cm wide, dogs' weight 10 kg (1), sphere volume  $V_{sph1} = 1500 \text{ cm}^3$ , shielded volume  $V_{sh1} = 992 \text{ cm}^3$   
 $\Delta_2$ ) same as  $\Delta_1$ , but for dogs weighing 12 kg (2),  $V_{sph2} = 1800 \text{ cm}^3$ ,  $V_{sh2} = 1160 \text{ cm}^3$

It was also established on the carcasses of 18 dogs that the overall mass of internal organs of the abdominal region (spleen, both kidneys and adrenals, pancreas, liver with gallbladder, stomach and intestine, bladder) constitutes an average of 15% (12-18.5%) of total body weight without consideration of correlation with the dogs' age, and their specific weight can be considered to be 1. Accordingly, in constructing the forecast model, we took 15% of total body weight as the volume of viscera in the dogs' abdominal region. The forecast was made for spheres 1500 and 1800  $\text{cm}^3$  in size for dogs weighing 10 and 12 kg, respectively.

Rather good agreement was obtained when we compared the estimated values to results of experimental studies (see Table). Consequently, we can state that the model we propose has a good prognostic capability on the basis of mean absorbed dose in the abdominal region in order to predict vomiting with the primary reaction of dogs exposed to radiation in doses not exceeding 800 R.

The discrepancies that do exist between the digital results of experimental and estimated data are perhaps related to the rather arbitrary use of a sphere to approximate the abdominal region. With the identical localization of the shield in the experiment and model (central part of the abdomen), there are some differences in quantitative and qualitative composition of protected parenchymatous organs (primarily the intestine), which determine the magnitude of the protective effect.

A somewhat different approach would perhaps be required to assess the efficacy of local shielding and construction of a model in the case of exposure to radiation in doses several times higher than the lethal dosage, since in such cases the effect would also be determined to a significant extent by the dose burden on unprotected parts of the body and functional importance of shielded organs.

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## CONDITION OF ERYTHROCYTES DURING LONG-TERM EXPOSURE TO MAGNETIC FIELD

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17,  
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[Article by G. V. Cherkasov]

[English abstract from source] During and after exposure to a constant magnetic field of 1.6 T mice showed variations in the size distribution of red blood cells, with their shape remaining unchanged and enlarged cells being predominant. This shift persisted till exposure day 10 and began to return to normal on days 15, 22 and 30. After irradiation the Price-Jones curve varied in a different manner and recovered by day 6. The changes in the curve were not correlated with variations in the reticulocyte and erythrocyte counts or hemoglobin content. It is concluded that an exposure to a constant magnetic field produces insignificant lesions in the red blood cell membrane. Mention should be made of a reduction of the reticulocyte count in the peripheral blood after exposure.

[Text] It is known that there is increase in peripheral blood reticulocyte content and elevation of erythropoietic titer in response to exposure to a stationary magnetic field (SMF) [1-3]. These signs are indicative of the erythropoiesis-stimulating activity of magnetic fields. It is interesting to determine the triggering mechanisms of stimulation of erythropoiesis. One of them, as reported previously [4], could be development of tissular hypoxia under the effect of the SMF. On the other hand, it is known that activation of erythropoiesis is associated with increased destruction of red blood cells, which could not be a stimulus for more intensive erythrocyte production in itself. Erythrocyte destruction can be induced by the direct effect of SMF, as indicated by in vitro studies [5]. Our objective here was to determine whether it is possible for erythrodieresis to occur as a result of long-term exposure to high-intensity SMF.

#### Methods

We conducted the studies on 360 male F<sub>1</sub> mice. A magnetic field was generated with an SP-57A electromagnet, with 900 mm diameter of pole tips and 100-mm space between them. Magnetic induction of the field in a radius of 380 mm remained virtually constant, at 1.6T. The mice were placed for 30 days in the electromagnet space in plexiglas containers. Control animals were

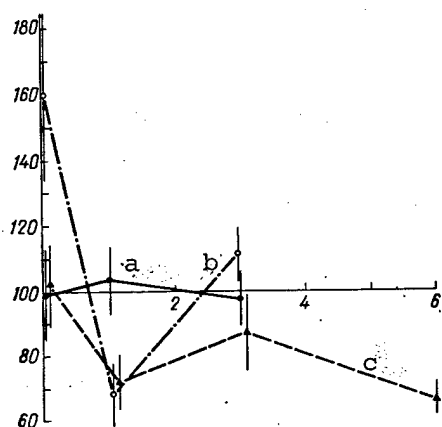
in an electromagnet phantom in the same type of container. Upkeep conditions were the same for control and experimental mice, providing good access of air and free movement. The electromagnet was turned off for 30 min each day to clean the containers and feed the animals. We took blood samples in the course of 30-day exposure to the field: after 3 h, then after 1, 4, 10, 15, 22 and 30 days. We examined the spectra of distribution of erythrocytes according to size, assayed hemoglobin, counted erythrocytes and reticulocytes. The same readings were taken in the aftereffect period on the 1st and 3d days after exposure for 3 h and 1 day, and on the 1st, 3d and 6th days after exposure for 30 days. The data for plotting Price-Jones curves were obtained using the celloscope of the AB Ljungberg Firm. We used the conventional method of automating cell counting. Cells were divided into macrocytes, microcytes and normocytes on the basis of closeness of the erythrocytometric curves to a gaussian curve [6]. Cells not exceeding the  $\pm 1\sigma$  range were classified as normocytes, those in the range of  $-1\sigma$  to  $-3.5\sigma$  and  $1\sigma$  to  $3.5\sigma$  made up to microcyte and macrocyte groups, respectively. Hemoglobin was measured with a Linson Junior colorimeter.

## Results and Discussion

Examination of the erythrocytometric curves plotted at different stages of exposure of the mice to SMF revealed that they were shifted to the macrocyte region, with no changes in shape of the curves. Such a shift was demonstrable already after 3-h exposure to the field. It reached a maximum by the 4th day. This was preceded by a phase of normalization of the erythrocytometric curve, which occurred on the 1st day of exposure to SMF. The quantity of macrocytes increased to  $30.59 \pm 0.68\%$  on the 4th day, versus  $24.64 \pm 0.68\%$  in the control ( $P < 0.001$ ), while microcyte count dropped to  $5.85 \pm 0.74\%$ , versus  $8.93 \pm 0.96\%$  in the control ( $P = 0.01$ ). By the 10th day of exposure, the shift in the curve persisted, macrocyte count in experimental mice constituted  $29.11 \pm 0.8\%$ , versus  $24.56 \pm 0.68\%$  in the control ( $P < 0.001$ ) and the figures for microcytes were  $7.07 \pm 0.93$  and  $8.64 \pm 0.88\%$ , respectively ( $P > 0.1$ ). However, in spite of continued exposure, the changes subsequently leveled off and there was complete normalization of the erythrocytometric curve. Table 1 lists data on distribution of erythrocytes according to size at different stages of exposure of mice to SMF. It shows that the erythrocytometric indicators did not differ from control values on the 15th, 22d and 30th days of exposure. In the aftereffect period, we again observed changes in the Price-Jones curve. One day after termination of exposure, macrocytes decreased to  $21.34 \pm 0.3\%$  (versus  $25.36 \pm 0.64\%$  in the control;  $P < 0.001$ ) and there was a tendency toward increase in microcytes to  $10.23 \pm 0.57\%$  ( $8.66 \pm 0.83\%$  in the control). On the 3d day, the curve shifted, this time in the direction of macrocytes. Their number constituted  $26.92 \pm 0.32\%$  and  $24.22 \pm 0.76\%$  ( $P < 0.002$ ) in the experiment and control, respectively, while microcytes constituted  $4.92 \pm 0.47$  and  $7.62 \pm 0.92\%$  ( $P < 0.01$ ). By the 6th postexposure day, the spectra of distribution of erythrocytes according to size in experimental animals did not differ from the control. Table 2 lists the relevant data. Changes in the erythrocytometric curve were also demonstrated after briefer exposure. The shift on the Price-Jones curve in the direction of macrocytes, which was observed immediately after termination of 3-h exposure, persisted for the next post-exposure days. As can be seen in Table 2, 1 day after exposure the quantity of macrocytes increased to  $26.75 \pm 0.72\%$  ( $24.78 \pm 0.53\%$  in the control;  $P < 0.05$ ),

while microcyte content dropped to  $6.81 \pm 0.6\%$  ( $9.33 \pm 0.83\%$  in the control;  $P < 0.02$ ). At the time of termination of 1-day exposure no change was noted in the erythrocytometric curve. In the aftereffect period, no changes were observed either on the 1st day. However, after 3 days we detected an increase in microcytes to  $13.01 \pm 0.69\%$ , versus  $10.72 \pm 0.73\%$  in the control ( $P < 0.05$ ).

There were changes in erythrocyte, reticulocyte and hemoglobin content in the course of 30-day exposure and in the aftereffect period, at some of the tested times. By the 10th day of exposure to the magnetic field, erythrocyte count rose to  $103.4 \pm 1.75\%$  ( $P < 0.05$ ) and on the 6th postexposure day to  $105.03 \pm 1.86\%$  ( $P < 0.01$ ), in comparison to the corresponding control. Hemoglobin rose to  $109.3 \pm 1.74\%$  ( $P < 0.001$ ) and  $104.7 \pm 1.59\%$  ( $P < 0.01$ ) on the 10th day of exposure and 6th postexposure day, respectively. There was a distinct increase in reticulocyte count of peripheral blood after exposure to SMF for 1 day, when they constituted  $159.9 \pm 24.9\%$  ( $P = 0.002$ ) of the corresponding control. At earlier stages (3 h) no increase in reticulocyte count was noted. Blood reticulocyte content rose again in experimental mice after exposure to SMF for 10 days, to  $123.76 \pm 15.99\%$ , as compared to the control. At other times, no differences were demonstrable between experimental and control mice with regard to reticulocyte count. When the animals were removed from the SMF they again presented changes in reticulocyte content, but they were in the opposite direction from those observed during exposure (see Figure). For



Reticulocyte content of peripheral blood after exposure to 1.6 T SMF for 3 h (a), 24 h (b) and 30 days (c).

Y-axis, % of control; x-axis, postexposure time (days)

the first 6 days after 30-day exposure, we observed a statistically reliable decline of reticulocytes in blood. They dropped to  $72.36 \pm 9.2\%$  ( $P = 0.01$ ) on the 1st postexposure day and to  $65.78 \pm 6.12\%$  ( $P < 0.001$ ) on the 6th day. A decrease in reticulocyte content to  $68.12 \pm 9.6\%$  ( $P < 0.01$ ), in relation to the control, was also noted 1 day after 24-h exposure. By the 3d day, the number of reticulocytes reached control values.

Thus, our data indicate that there is a change in the erythrocytometric curve, in the direction of increase in number of larger cells, under the effect of exposure to SMF of 1.6 T for 3 and 24 h, as well as 30 days. This increase cannot be attributed to an increase in number of reticulocytes, since the shift in the curve occurred before changes in reticulocyte content and it showed no correlation with their changes at

Table 1. Erythrocytometric parameters during 30-day exposure to SMF of 1.6 T

EXPOSURE TIME	AVERAGE DIAMETER OF ERYTHROCYTES $\mu\text{m}$		MACROCYTES %		NORMOCYTES %		MICROCYTES %	
	CONTROL	EXPERIMENT	CONTROL	EXPERIMENT	CONTROL	EXPERIMENT	CONTROL	EXPERIMENT
3 H	6.93 $\pm$ 0.115 (14)	7.00 $\pm$ 0.121 (14)	23.07 $\pm$ 0.63 (14)	25.43 $\pm$ 0.74* (14)	67.40 $\pm$ 1.3 (14)	66.24 $\pm$ 1.30 (14)	9.53 $\pm$ 0.81 (14)	8.33 $\pm$ 0.73 (14)
24 H	6.99 $\pm$ 0.161 (15)	7.04 $\pm$ 0.107 (15)	24.77 $\pm$ 0.92 (15)	26.14 $\pm$ 0.63 (15)	64.56 $\pm$ 1.7 (15)	64.57 $\pm$ 1.00 (15)	10.67 $\pm$ 0.81 (15)	9.29 $\pm$ 0.84 (15)
4 DAYS	6.74 $\pm$ 0.112 (5)	6.92 $\pm$ 0.123 (5)	24.64 $\pm$ 0.68 (5)	30.59 $\pm$ 0.68*** (5)	66.43 $\pm$ 1.2 (5)	63.56 $\pm$ 1.51 (5)	8.93 $\pm$ 0.96 (5)	5.85 $\pm$ 0.74** (5)
10 DAYS	6.83 $\pm$ 0.168 (5)	6.96 $\pm$ 0.112 (4)	24.56 $\pm$ 0.68 (5)	29.11 $\pm$ 0.80*** (4)	66.80 $\pm$ 2.1 (5)	63.82 $\pm$ 1.00 (4)	8.64 $\pm$ 0.88 (5)	7.07 $\pm$ 0.93 (4)
15 DAYS	6.54 $\pm$ 0.207 (4)	6.54 $\pm$ 0.270 (5)	22.53 $\pm$ 0.50 (4)	24.61 $\pm$ 1.68 (5)	68.14 $\pm$ 2.6 (4)	66.61 $\pm$ 3.36 (5)	9.33 $\pm$ 2.18 (4)	8.78 $\pm$ 1.71 (5)
22 DAYS	6.77 $\pm$ 0.121 (10)	6.71 $\pm$ 0.142 (10)	24.87 $\pm$ 0.70 (10)	22.99 $\pm$ 0.71 (10)	67.01 $\pm$ 1.3 (10)	68.01 $\pm$ 1.67 (10)	8.12 $\pm$ 0.80 (10)	9.00 $\pm$ 0.92 (10)
30 DAYS	6.80 $\pm$ 0.075 (8)	6.77 $\pm$ 0.113 (10)	25.66 $\pm$ 0.37 (8)	25.00 $\pm$ 0.59 (10)	64.97 $\pm$ 0.9 (8)	65.32 $\pm$ 1.27 (10)	9.37 $\pm$ 0.56 (8)	9.68 $\pm$ 0.69 (10)

\*P&lt;0.02

\*\*P&lt;0.01

\*\*\*P&lt;0.001

Note: Here and in Table 2 the number of animals is given in parentheses.

Table 2. Erythrocytometric parameters after exposure to SMF of 1.6 T for different periods of time

TEST DAY	AVERAGE DIAMETER OF ERYTHROCYTES $\mu\text{m}$		MACROCYTES %		NORMOCYTES %		MICROCYTES %	
	CONTROL	EXPERIMENT	CONTROL	EXPERIMENT	CONTROL	EXPERIMENT	CONTROL	EXPERIMENT
1	6.96 $\pm$ 0.120 (14)	7.05 $\pm$ 0.129 (13)	24.78 $\pm$ 0.53 (14)	26.75 $\pm$ 0.72* (13)	65.89 $\pm$ 1.30 (14)	66.44 $\pm$ 1.40 (13)	9.33 $\pm$ 0.83 (14)	6.81 $\pm$ 0.60* (13)
3	6.94 $\pm$ 0.119 (15)	6.92 $\pm$ 0.113 (14)	24.68 $\pm$ 0.54 (15)	24.01 $\pm$ 0.50 (14)	66.09 $\pm$ 1.30 (15)	65.96 $\pm$ 1.30 (14)	9.23 $\pm$ 0.67 (15)	10.03 $\pm$ 0.72 (14)
1	6.93 $\pm$ 0.104 (12)	6.98 $\pm$ 0.146 (14)	23.67 $\pm$ 0.53 (12)	25.27 $\pm$ 0.74 (14)	66.56 $\pm$ 1.10 (12)	65.45 $\pm$ 1.60 (14)	9.77 $\pm$ 0.76 (12)	9.28 $\pm$ 0.90 (14)
3	7.05 $\pm$ 0.120 (10)	7.01 $\pm$ 0.085 (10)	24.89 $\pm$ 0.68 (10)	24.71 $\pm$ 0.66 (10)	64.39 $\pm$ 1.00 (10)	62.28 $\pm$ 1.20 (10)	10.72 $\pm$ 0.73 (10)	13.01 $\pm$ 0.69* (10)
1	6.78 $\pm$ 0.134 (9)	6.67 $\pm$ 0.076 (10)	25.36 $\pm$ 0.64 (9)	21.34 $\pm$ 0.30*** (10)	65.98 $\pm$ 1.58 (9)	68.43 $\pm$ 0.96 (10)	8.66 $\pm$ 0.83 (9)	10.23 $\pm$ 0.57 (10)
3	6.73 $\pm$ 0.123 (7)	6.84 $\pm$ 0.064 (9)	24.22 $\pm$ 0.76 (7)	26.92 $\pm$ 0.32*** (9)	68.16 $\pm$ 1.33 (7)	68.16 $\pm$ 0.71 (9)	7.62 $\pm$ 0.92 (7)	4.92 $\pm$ 0.47** (9)
6	6.68 $\pm$ 0.07 (9)	6.67 $\pm$ 0.074 (10)	24.40 $\pm$ 0.24 (9)	24.04 $\pm$ 0.38 (10)	68.12 $\pm$ 0.88 (9)	68.40 $\pm$ 0.94 (10)	7.48 $\pm$ 0.77 (9)	7.56 $\pm$ 0.66 (10)

\*P&lt;0.05

\*\*P&lt;0.01

P&lt;0.002

\*\*\*P&lt;0.001

A decrease in resistance of red blood cells to acid hemolysis with exposure to SMF of lower levels (0.5 T) was reported previously [2]. According to other data, at the indicated intensities of SMF, such signs of deleterious effects of SMF as changes in erythrocyte life span [7], impairment of energy metabolism, ion transport in erythrocytes were not demonstrable in experiments in vitro [8]. However, we cannot rule out the possibility of disturbances in metabolic processes of erythrocytes and their role in changing functional activity of the erythrocyte membrane under the effect of the stronger SMF used here. This could be indicated, in particular, by data on impairment of peroxidation of lipids, which are an important structural component of the erythrocyte membrane [9]. It can be assumed that the shift of the erythrocytometric curve is attributable to change in physicochemical properties of blood plasma, in addition to the direct damaging effect of SMF on the erythrocyte membrane. The findings concerning erythron reaction in the aftereffect period are very interesting. A decrease in reticulocyte content occurs after both brief (24 h) and prolonged (30 days) exposure. With increase in exposure time, there is increase in period of reticulocytopenia, with unchanged magnitude of reaction. The decrease in number of reticulocytes could be related either to depression of erythropoiesis or faster maturation of young erythrocytes and release of more mature cells from bone marrow into peripheral blood. This question requires special investigation.

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## CLINICAL STUDIES

UDC: 613.693-07:[616.85-036.86-092:612.821

### EXPERIMENTAL PSYCHOLOGICAL METHODS USED IN EXPERT EVALUATION OF MENTAL WORK CAPACITY OF FLIGHT PERSONNEL IN THE PRESENCE OF FUNCTIONAL DISTURBANCES AND CENTRAL NERVOUS SYSTEM DISEASES

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 28 Jan 82) pp 76-80

[Article by I. N. Lavrent'yeva, V. I. Myasnikov and V. F. Volokhov]

[English abstract from source] The study of mental performance of the flying personnel during medical expertise with respect to complex sensory-motor and logical operations has shown that changes of psychic activity in subjects with early symptoms of cerebral atherosclerosis are more marked than those in subjects with CNS functional disorders. They involve difficulties in attention control, delay in motor responses, deterioration in associative processes. These subjects prove less suitable for flying work: 71% of the pilots examined were grounded by the medical expertise.

[Text] Flying is among the most difficult types of operator work, and it imposes great demands on the neuropsychological system of flight personnel [1]. As previously noted [2], flights are always related to the unexpected and risk; they bring out a man's capabilities, his "psychological reserve." At the same time, the high psychoemotional tension due to flight work factors is among the basic causes of various functional disturbances and CNS [central nervous system] diseases [3-5]. For this reason, it is becoming a particularly pressing matter to develop psychological methods of determining the condition of the CNS and expert evaluation of work capacity of flight personnel in the practice of expert medical certification of pilots (EMCP).

Our objective here was to examine the mental state and work capacity of flight personnel with functional CNS disturbances such as neurotic reactions, asthenoneurotic states, emotional and vascular instability, and early signs of cerebrovascular atherosclerosis, on the basis of assessing the professionally relevant traits and properties (resistance to interference, ability to switch attention rapidly, coordination of movements when time is limited and short, etc.) with simulation of some elements of a pilot's professional performance in the course of EMCP.

## Methods

The studies were conducted on 136 pilots 32-38 years of age, who were in the hospital for examination. Of this number, 59 were essentially healthy (first group, control), 47 had functional CNS disorders (second group) and 30 had early signs of cerebrovascular atherosclerosis (third group). Concurrently, in order to validate the most effective programs when working with instruments to test complex sensorimotor reactions (CSMR) and complex mental logic operations (CML0), as well as to elaborate rating scales, an additional series of studies was performed on 145 and 86 people using each of the above instruments, respectively.

The CSMR instrument is designed in the form of a console, on the front panel of which there are 10 slots in the form of arrowheads at the top (in a row) and 10 keys at the bottom (opposite the slots). According to the instructions, the subject was presented with a series of successive light signals, in response to which he had to react as quickly as possible by depressing the appropriate key. The photic stimuli were delivered in random order at the rate of 93/min (first mode), 107/min (second mode) and 125/min (third mode).

Performance was assessed according to an overall indicator of correct answers.

Before starting the test, there was a half-min practice session with the subject, during which photic stimuli were delivered at the rate of 60/min.

The CML0 instrument made it possible to deliver color and audio signals at 3.5-s intervals. Signal was exposed for 1 s. The subject had to react to the signals by means of the manual keys and foot pedals, in accordance with the program of the study. We used three programs: practice, during which 10 successive color signals and low-frequency sounds were delivered; control, which was similar to the first, but involved delivery of 30 signals, and the test program, which consisted of 33 signals but, unlike the first two, involved the following: a) need to react not only to successive, but simultaneous delivery of color signal and low-frequency sound; b) possibility of delivery additional information--high-frequency sound (12 signals), a response to which was recorded as a mistake.

As criteria for evaluating the quality of performance we used overall time, number of correct reactions and erroneous actions of three types: 1) absence (miss) or delay (more than 1 s) in response; 2) inadequate reaction; 3) response to signal that did not require a reaction (paradoxical reaction).

The above-mentioned criteria for rating performance were chosen on the basis of preliminary analysis of operator errors, which revealed that 50-70% are referable to errors of the first and second types [6].

The results of these tests were submitted to statistical processing, with use of  $\chi^2$ , F and t criteria, as well as the symbolic rank criterion of Wilcoxon and U criterion on a minicomputer according to specially prepared programs.

## Results and Discussion

Analysis of flight performance, results of clinical and psychological work-up revealed that the group of subjects, regardless of reason for being at the hospital (expert certification, treatment), was outstanding for high motivation for flight work and responsible attitude toward the tests.

The pilots undergoing routine medical certification (first group) were characterized by rapid development of the specified stereotype of activity when working on the CSMR and CML0 instruments, they had well-developed operator qualities, emotional stability throughout the study and high productivity of work. They had high scores for performance quality on the CSMR instrument, regardless of speed of presentation of photic signals, with concurrent lower values for average correct reaction time, small number of delayed and inadequate responses when following programs of work on the CML0 instrument that differed in difficulty.

The second group of subjects (36% with neurotic reactions, 38% with asthenoneurotic states and 26% with emotional-vascular instability) were, on the contrary, notable for emotional lability, unstable affect, impulsiveness and lack of restraint in behavior, increased fatigability, sleep disorders, most often in the form of presomnial disturbances, etc. When working on the CSMR instrument, an increase in rate of delivery of photic stimuli from 93 to 125/min elicited a drastic worsening of performance quality in these subjects, which was manifested by a decrease in frequency of correct responses, from  $0.812 \pm 0.048$  to  $0.219 \pm 0.031$  (Table 1).

Table 1. Mean frequency of correct responses of subjects working on CSMR instrument as a function of speed of delivery of photic signals ( $\bar{X} \pm m$ )

Group	Rate of delivery of photic signals, per min		
	93	107	125
1	$0.904 \pm 0.024$	$0.784 \pm 0.044$	$0.408 \pm 0.042$
2	$0.812 \pm 0.048^*$	$0.547 \pm 0.065^{**}$	$0.219 \pm 0.031^{**}$
3	$0.789 \pm 0.046^*$	$0.544 \pm 0.046^{***}$	$0.201 \pm 0.024^{***}$

Note: Reliability of differences is shown in comparison to parameters for the first group of subjects. Here and in Table 2:

\* $0.01 \leq p < 0.05$

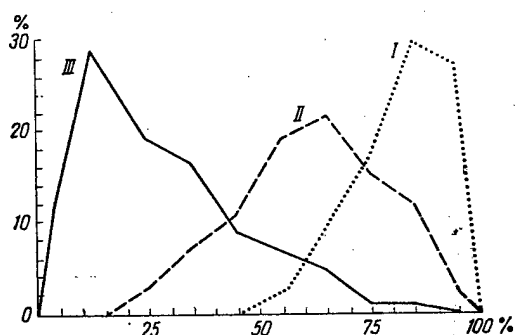
\*\* $0.001 \leq p < 0.01$

\*\*\* $p < 0.001$

Working within a limited time was associated in these cases with development of psychoemotional tension, which was outwardly manifested not only by worsening of quality of specified performance, but change in behavior (impaired coordination, verbal reactions, etc.), development of vegetovascular reactions (systemic and distal hyperhidrosis, change in heart and respiration rate, blood pressure). In 5 cases out of 25, the subjects were unable to continue working with the instrument and refused to perform the test. When

meaningful information delivery rate was 125/min, results were almost one-half the performance of the control group. This could be attributed to the fact that good performance with the instrument is determined not only by simple visual and motor operations (on the level of direct connection), but capacity for long-term continuous work when information is delivered at a rapid pace, i.e., preservation of mental processes that are most likely to be impaired when there are functional CNS diseases [5, 7-9].

A comparative study of the psychological difficulty of working with the CSMR instrument by methods of statistical analysis revealed that the most effective test programs are conditions of work when meaningful information is delivered at the rate of 107 and 125 cues/min. The polygon of distribution of frequency of correct reactions (see Figure) with photic signals delivered at



Polygons of distribution of frequency of correct responses of flight personnel as related to different rates of delivery of photic signals.

X-axis, frequency of correct responses (%); y-axis, number of tested subjects

I-III) photic signals delivered at rates of 93, 107 and 125/min, respectively

the rate of 93/min presented negative asymmetry with a close to maximum value of the sample mean (85%) and low standard deviation ( $S = 12.46\%$ ), which is indicative of the fact that work at this speed is not difficult enough for this category of subjects. Delivery of photic signals at the rate of 107 and 125/min had the greatest differentiating capacity ( $S = 18.58$  and  $18.05\%$  for 107 and 125 signals/min, respectively), and these rates were more significant to evaluation of functional capabilities of the operator. This was also indicated by the coefficients of variation of number of correct responses, which constituted 14.7, 28.7 and 63.5%, with signals delivered at the rate of 93, 107 and 125/min, respectively. Criterion  $\chi^2$  showed a high degree of agreement of empirical distribution of results with normal distribution in the case of delivery of 107 signals/min and with logarithmically normal distribution in the case of 125/min. Nine-point rating scales for EMCP purposes were prepared on the basis of adopting these hypotheses on distribution.

With the turn to more difficult forms of operator work (work on CMLO instrument), there was a statistically significant decline in frequency of correct responses with concurrent increase in number of skipped answers, as compared to productivity of the first group of subjects (Table 2). The significance of differences from parameters for the first group of subjects increased as work became more complicated (i.e., when changing from the control to the test program), from 0.01-0.05 to 0.001. Higher indicators of inadequate and paradoxical reactions were inherent in the second group of subjects, and this confirms the numerous data indicative of weakening of internal inhibition (according to I. P. Pavlov) in patients with functional CNS diseases and prevalence of an excitatory process inherent in the early stage of disease, in the balance of basic nervous signs.

Table 2. Parameters of performance on CML0 instrument by pilots with different functional disturbances and diseases of the CNS

Work program		Average correct reaction time, s	Mean reaction frequency, %			
			correct	missed	inadequate	paradoxical
Practice	1	0,604±0,032				
	2	0,592±0,024				
	3	0,672±0,014*				
Control	1	0,603±0,016	91,0±3,70	1,0±0,92	8,0±3,48	—
	2	0,604±0,021	82,2±3,98	7,2±2,48*	10,6±2,14	—
	3	0,643±0,030	81,6±1,63*	9,4±2,90**	10,0±1,92	—
Test	1	0,730±0,016	77,2±4,99	12,6±3,40	10,2±3,97	4,0±2,00
	2	0,723±0,019	56,3±2,89***	28,2±2,89***	15,5±2,25	11,1±6,52
	3	0,753±0,022	50,0±4,00***	37,3±4,12***	12,7±3,88	7,4±5,51

Note: Frequency of paradoxical reactions is considered in relation to total number (12) of high-frequency audio signals

Preliminary statistical analysis of the differentiating capacity of work programs with the CML0 instrument according to time and quality characteristics of performance revealed that the third, test program has the highest such capacity. The most effective indicators of performance, when comparing the groups studied, are accuracy and quality of fulfilling program, rather than time. Analysis of the relationship between performance parameters for the control and test programs revealed that there is no correlation between average correct reaction time and frequency of correct responses. At the same time, we found a mild negative correlation ( $r = 0.329$ ,  $P < 0.01$ ;  $r = 0.242$ ,  $P < 0.05$  for control and test programs, respectively) with frequency of appearance of inadequate reactions. This was also indicated by the findings of other authors [10, 11].

In the course of the study, the third group of subjects presented emotional tension, lability of work pace, unstable formation of sensorimotor skill when it was necessary to perform a specified activity for a relatively long time.

Analysis of the results listed in Tables 1 and 2 shows that this nosological group of patients is characterized as a whole by lower base parameters, as compared to the control group, for quality of performance, with regard to number of correct responses on the CSMR instrument and frequency of missed and inadequate responses on the CML0 instrument. Differentiation of the compared groups becomes more accentuated with increase in rate of delivery of photic signals and in difficulty of the work. These patterns are apparently attributable to the general mental state which, according to the data in [12], is characterized by difficulty in switching attention, its distinctive "tenacity," slowness of motor reactions, etc., in patients with early signs of cerebrovascular atherosclerosis, in spite of their relative youth. The increase in reaction time, number of skipped and

delayed responses in the third group of patients, as compared to the first and second groups of subjects, could be attributed to increased inertness of mental processes, decrease in their flexibility, worsening of mnemonic parameters of mental activity, which renders this group of patients less likely to continue with flying work. This is indicated by the EMCP findings: 71% of the screened individuals were deemed unfit for flight work.

Thus, use of CSMR and CMLO instruments in EMCP practice reveals the individual capabilities of flight personnel with different CNS diseases, with respect to performance of complicated forms of sensorimotor work, logic operations and makes it possible to gain additional information characterizing the "psychological content" of disease. This, in turn, enables the expert to determine more precisely the work capacity of the subject and efficacy of therapeutic and preventive measures.

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## METHODS

UDC: 613.693+629.78]:[612.789:612.858.78

### OBJECTIVIZATION OF EVALUATION OF SPEECH INTELLIGIBILITY DURING FLIGHTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 22 Nov 82) pp 80-81

[Article by M. V. Frolov, O. A. Cherkasov, G. I. Tarasenko and I. A. Petlenko]

[Text] Problems of improving intelligibility of speech transmitted via radio communication channels with increasing complexity of individual systems of verbal communication (breathing masks, space suits, etc.) are becoming increasingly pressing.

The principal element that imparts to voice its tonal quality, forms its volume and, mainly, forms the sounds of speech is the so-called extension tube of the peripheral vocal system, which consists of the pharynx, buccal and nasal cavities. Any deliberate intervention in the function of active articulators leads to undesirable changes in the process of sound formation and control of resonators of the extension tube [1, 2]. As a result, the formed sounds of speech (phonemes) become distorted, and this affects the intelligibility, which is assessed by the results of auditor analysis.

It must be noted that evaluation of intelligibility by auditors is subjective. Although such evaluation has been approved by GOST-72, there are a number of factors that have an appreciable influence on its stability: individual distinctions of the acoustic analyzer of the auditor, his psychophysiological state and attitude toward the individual he is testing, level of motivations, etc. This is why questions of objective evaluation of intelligibility of speech are quite pressing. In order to achieve objectivity, it is proposed that, along with speech analysis by an auditor, there be monitoring of changes in parameters describing filtering function and source of sound in the speech-forming tract.

The work done with regard to combined analysis of the results of monitoring by an auditor and checking parameters of the articular tract of the speaker was aimed at searching for a more reliable and effective means of evaluating intelligibility of speech.

#### Methods

A study was made of the effect of a small confined space [mask] on syllable intelligibility of speech. Such confinement adds distortions to the function of

active articulators due to appearance of an additional resonator that interacts with the resonators of the buccal cavity and nasopharynx. Experiments were performed, in which a speaker read syllable tables in a masked-confined space. Verbal signals were recorded via a "microphone-intercom-tape recorder" line, on magnetic tape for subsequent analysis and expert evaluation of intelligibility by an auditor. In the course of a specific test, the speaker read two syllable tables, each of which consisted of 50 syllables. In the course of the experiments, we tested six types of masks with inside size of 80 to 270 cm<sup>3</sup>.

We selected as parameters of the state of the voice source and nasopharyngeal resonators the frequency of fundamental tone  $F_{ft}$  and mean number of inter-sections of zero level by the speech process per unit time  $\bar{n}(0)$  (number of zeroes), respectively. The latter parameter enables us to evaluate in the first approximation the position of the first formant of the speech-producing tract on the frequency axis. A mathematical description of the methods of singling out these parameters and their interpretation are given in [3-5]. In order to determine the causes of change in intelligibility and to find its optimum as a function of the parameters of the confined space, we studied the parameters of intelligibility of syllables-- $\bar{S}$ ,  $F_{ft}$  and  $\bar{n}(0)$ . We analyzed data for four speakers, who articulated a total of 12 syllable tables each using masks with different sized interior areas.

### Results and Discussion

Figure 1 illustrates curves characterizing changes in  $\bar{S}$ ,  $\bar{F}_{ft}$  and  $\bar{n}(0)$  standardized to their maximum values over the period of the experiment, which were obtained in testing different masks.

Parameters  $\bar{S}$ ,  $\bar{F}_{ft}$  and  $\bar{n}(0)$  are plotted on the y-axis, while parameter  $N$ , which refers to the number of the tested mask, is plotted on the x-axis. The numbers on the x-axis correspond to the following mask volumes: 1--80 cm<sup>3</sup>, 2--95, 3--145, 4--195, 5--250 and 6--270 cm<sup>3</sup>.

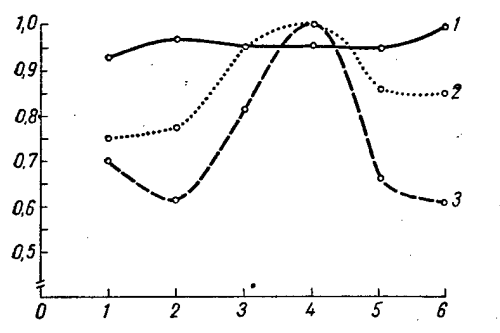


Figure 1.

Normalized mean frequency of fundamental tone ( $F_{ft}$ ), frequency of zeroes  $\bar{n}(0)$  and intelligibility ( $\bar{S}$ ) as a function of space under mask,  $N$

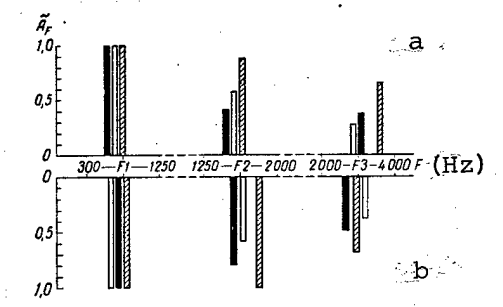


Figure 2.

Changes in formant structure of speech signals for two readers, (a) and (b)



According to analysis of the curves in Figure 1, there was insignificant change in frequency of fundamental tone, as compared to the average number of zeroes. This is due to the relatively minimal influence of the breathing mask on the source of voice, which is minimally related to nasopharyngeal resonators.

Maximum deviations were referable to the  $\bar{n}(0)$  curve, which changed in the same way as the  $\bar{S}$  curve. Curves  $\bar{n}(0)$  and  $\bar{S}$  have maximums in the range of  $N = 4$ . With increase in parameter  $N$  or its decrease in relation to the optimum ( $N = 4$ ), parameters  $\bar{S}$  and  $\bar{n}(0)$  decline. This decrease reaches 40% for  $\bar{n}(0)$ , with both increase and decrease in mask space. At the same time, parameter  $\bar{S}$  decreases by 25% in the case of  $N = 2$  and by 15% with  $N = 6$ . Consequently, the resonance nature of curves  $\bar{S}$  and  $\bar{n}(0)$  is determined by the effect of the undermask space.

Additional studies were made of the formant structure of the analyzed vowel sounds "a" [ah] and "o" to examine the mechanisms of intelligibility in the optimum case ( $N = 4$ ), as well as with worsening ( $N = 2$ ,  $N = 6$ ). We paid attention mainly to the correlation between the 2d, 3d and 1st formants. It is known that intelligibility of vowel phonemes depends on the level of the 2d and 3d formants and their volume depends on the 1st formant [1, 6].

The results of studies of location of formants in frequency ranges and amplitude are illustrated in Figure 2, where  $\bar{A}_F$  is used to designate the values of formant maximums in relation to the level of the 1st formant.  $F_1$ ,  $F_2$  and  $F_3$  refer to the position of the formants in the corresponding frequency ranges.

The formant structure for optimum intelligibility ( $N = 4$ ) is illustrated by the hatched bars, in the situation of  $N = 2$  by the black bars and the case of  $N = 6$  is shown by the white bars.

Analysis of Figure 2 shows that, in both cases, (Figure 2a and 2b), maximum syllabic intelligibility corresponds to highest levels of the 2d and 3d formants. In the case of diminished intelligibility ( $N = 2$ ,  $N = 6$ ), the levels of the 2d and 3d formants drop significantly, as compared to analogous situations with  $N = 4$ . These differences are significant at a level of  $P = 0.05$  [7].

According to analysis of Figure 2, in the situation of maximum intelligibility of syllables, the first formant is shifted to the right on the frequency axis to a greater extent than in the other cases ( $N = 2$ ,  $N = 6$ ). In a number of instances, this fact can serve as grounds to assess the quality of syllable intelligibility only on the basis of the average number of zeroes (without estimating the 2d and 3d formants) when a reader articulates in a small confined space.

It can be stated that we demonstrated the high informativeness of average number of zeroes  $\bar{n}(0)$  in analyzing speech intelligibility for the tested sizes of confined spaces.

On the one hand, parameter  $n(0)$  is closely related to the formant (spectral) structure of the verbal signal and, on the other hand, it is well-correlated with the results of an auditor's evaluation of intelligibility of syllables.

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DETERMINATION OF A SUBJECT'S CONDITION ACCORDING TO PITCH OF THE VOCAL VOWEL 'A'

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 31 Mar 82) pp 82-83

[Article by G. I. Akinshchikova and O. D. Volchek]

[Text] One of the most important prerequisites for reliability of operator performance is proper and prompt determination of his condition. Among the noncontact methods of state diagnosis, the method of analysis of the verbal signal is used extensively, in particular, the pitch of the fundamental tone of speech (PFT). In view of the absence of reliable correlation between a change in PFT and change in an individual's condition, as well as the need to shorten diagnosis time, it is a pressing task to search for new and more refined methods.

It is known that vocal speech has high emotional expressiveness [1], and this applies in particular to vocal vowels [2]. Our objective here was to determine the informative role of pitch of the vocal vowel "A" (PVV"A"). We chose this vowel because there are optimum energy and dynamic characteristics to its phonation, and it is used the most, as compared to other vowels, which is not by chance. It is expressly the vowel "A" that is phylogenetically the oldest [3, 4].

Investigation of the informative role of PVV"A" involved the study of the influence of the environment, emotional state and individual distinctions on it.

#### Methods

We recorded phonation of "A" by more than 200 individuals under different conditions: at different times of day and year, in a situation of increased loads (stress and fatigue), with simulation of emotional states of grief, anger, joy, fear and a neutral state. Most of the subjects had no musical education (27 had had more than 5 years of musical education, and 7 of them were professional musicians). The subjects' average age was 30 years.

We obtained more than 3000 records of phonation of "A" on a Kometa-212 stereo tape recorder. The main instructions were to sing the vowel "A" naturally, without straining, with a comfortable sensation in the laryngeal region.

Analysis of values of PVV"A" was made by the method of beats [5, 6]. Margin of error of measurements constituted 2-10% (about 0.5-3 Hz).

Concurrently, we recorded the pulse, reproduction of 20-s time interval and SAN (well-being, activity and affect). Luscher's (8-color), Eysenck's (form A) and Cattell's (form C) tests were performed on all of the subjects.

### Results and Discussion

It was found that the magnitude of PVV"A" is a reflection of complex interaction between several factors. Ambient conditions determine the initial level, the background against which PVV"A" changes depending on emotional state, conditions of activity and individual distinctions of a person. As a result of correlation analysis of the results of our studies, a close link was demonstrated between magnitude of PVV"A" and values of some psychophysiological parameters--pulse, reproduction of time interval, SANrating. The level of significance constituted  $P = 0.01-0.001$ .

It was established that the nature of changes in PVV"A" is attributable to such individual human distinctions as sex, age, extraversion-introversion, neuroticism, reactivity [7] and others. The narrowest range of fluctuations of PVV"A", 8-10 Hz, was noted in the male subjects with very distinct extraversion and low parameters of neuroticism. However, in such cases, a change in state was also well-manifested by other changes in parameters of the vowel "A"--volume, stability of phonation, attack, modulation and duration. The frequency at which the values of PVV"A" fall into different ranges [8] also depends on a person's individual distinctions and could serve as a sort of characteristic. In this case, it is warranted to make use of already available information about the meaning of tonalities [9, 10].

It was found that there is an element in common in the informative role of PVV"A" under certain conditions and meaning of the corresponding tonality in music. For example, it was previously shown that tonality can be viewed as a sort of indicator of an individual's psychophysiological condition under certain ambient conditions [9, 10]. Thus, there is partial confirmation of the thesis that there is something in common between the acoustic language of emotions in song, speech and music [1, 11]. Consequently, we could expect a reflection of the effect of the environment in acoustic parameters of speech also.

The results of this study revealed that it is possible to determine an individual's state according to the PVV"A". Additional analysis of its other parameters permits an adequate evaluation of condition. In the case of using automated methods of analysis of acoustic parameters of speech, the time required to make such determination is reduced to a few seconds.

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## METHOD FOR ASSESSING MENTAL STRESS IN OPERATORS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 15 Nov 82) pp 83-84

[Article by B. N. Ryzhov and V. P. Sal'nitskiy]

[Text] One of the important problems of modern psychophysiology is that of making an objective assessment of operators' mental tension. Along with the qualitative analysis of autonomic parameters of tension used traditionally, in recent times the approach to such evaluation by means of analysis of statistical characteristics of some function, which is considered the most informative under the conditions being considered, has gained wide use [1, 2]. However, use of an autonomic parameter alone is not enough for reliable qualification of mental states that occur in the course of work. For expressly this reason, several methods have been proposed, which are based on consideration of quantitative parameters of several psychophysiological functions. Among them, the method of combining different parameters into an integral evaluation of stress has gained the widest use [3, 4].

At the same time, the practical use of this method encounters a number of difficulties, both with regard to interpretation of results (since it is impossible to construct a single scale of ratings of tension level) and when comparing data obtained for different operators. All this justifies the attempt to further modify the method of assessing the level of mental tension in operators.

## Methods

We have proposed the following as elements of an integral evaluation of mental tension: 1) increments in current and 2) maximum permissible values for psychophysiological parameters in relation to background values. Quantitative evaluation of mental tension ( $\gamma_{mt}$ ) is made using the following equation:

$$\gamma_{mt} = \sqrt{\frac{1}{n} \sum_{i=1}^n \left( \frac{x_i - x_i^{\phi}}{x_i^{\max} - x_i^{\phi}} \right)^2}, \quad (1)$$

where  $x_i$  is the current value of the  $i$ th psychophysiological parameter,  $x_i^{\max}$  is maximum permissible and  $x_i^{\phi}$  background value of this parameter,  $n$  is the number of psychophysiological parameters. One can determine  $x_i^{\max}$

on the basis of statistical processing of data gathered previously for each operator; if none is available one can take the values recommended in the literature as maximum permissible levels [5, 6].

The evaluation of mental stress made in accordance with equation (1) is unrelated to fluctuations of background values of the different parameters it contains, so that more consideration can be given to the law of base values of Wilder, which postulates that there is nonlinear relationship between the level of mental tension in a subject and physiological changes observed [7]. At the same time, as it changes from zero (in the absence of physiological signs of tension) to 1 (with maximum intensity of such signs),  $\gamma_{mt}$  is a rather convenient quantitative gauge of the psychophysiological expenditure made by man during performance of difficult work.

In order to examine the diagnostic capabilities of the method, we conducted a cycle of studies of functional state of operators working under conditions of changing information load. The cycle consisted of three series of tests, which differed in extent of similarity of actual working conditions for operators of dynamic systems. The first series was concerned with work with instrument information, while the second and third were conducted using half-scale models of a system of manual control of an aircraft (the technical conditions of these studies were described in detail previously [8]). To assess the level of mental stress in operators, as individual psychophysiological parameters we used the heart rate (HR), respiration rate (RR), minute volume (MV), temperature of dorsum of the hand ( $t_h^o$ ), electrodermal resistance (EDR), overall energy of  $\theta$ - and  $\beta_2$ -rhythms of bioelectrical activity of the brain (EEG). We tested 70 healthy men 20-45 years of age.

## Results and Discussion

The validity of the method was determined in the first series of studies by finding coefficients of correlation ( $r_i$ ) between parameters of tension and rate of delivery of information to the operator, which was in the range of 3-3 bits/s (to determine  $r_i$  all of the data were averaged for a 1-min interval). In the second and third series, we used parameter  $d_i$ , which is known from theory of signal detection and reflects the degree of variability of each parameter of tension when changing from standard working conditions to fixed increase in dynamic characteristics of the controlled object. It is apparent from the data listed in the table that the informativeness of results obtained by the method of integral evaluation exceeded in all cases the informativeness of specific evaluations. It is important to note that, in some of the tested operators, some function could be closely correlated with intensity of existing stress factor; however, the advantage of the integral method became obvious according to the entire aggregate of data.

Investigation of parameters of productivity of operator work, distinctions of their reactions during work, as well as their own accounts enable us to demonstrate a rather high discriminatory sensitivity of the integral rating for qualitatively dissimilar types of mental tension that are inherent in the types of operator work in question.

As shown by this study, the range of values of  $\gamma_{mt}$  not exceeding 0.2-0.25 arbitrary units corresponded to dominance of the operational type of tension. In

Comparative informativeness of parameters of mental tension under different conditions of operator work

SERIES	INFORMATIVENESS	PARAMETERS OF MENTAL STRESS						
		HR/MIN	RR/MIN	$t_{\text{h}}$	MY L/MIN	EDR (KΩ)	EEG ARB UNIT	$\gamma_{\text{mt}}$ ARB. UNITS
I	ri	0,67	0,67	0,50	0,60	—	—	0,80
II	di	0,56	0,62	—	—	0,41	—	0,64
III	di	0,56	0,85	—	—	—	0,63	0,89

this case, work proceeded without marked disturbances of algorithm, and it was not associated with vivid emotional reactions if mistakes were discovered. In many cases, appearance of gross errors coincided with elevation of parameter  $\gamma_{\text{mt}}$  beyond the level of 0.2-0.25 arbitrary units. Impaired performance, supplemented by the operators' own accounts, as well as the observed changes in frequency spectrum of the EEG (depression of superfast activity of the brain against a background of drastic increase in share of slow waves, primarily  $\Theta$ -rhythm), warrant consideration of the range of 0.2-0.25 arbitrary units for values of  $\gamma_{\text{mt}}$  as the limit, exceeding which is indica-

tive of development of a state of negative emotional stress. The inadequacy of operator behavior to the situation, which was present with  $\gamma_{\text{mt}} = 0.4-0.5$ , enables us to state that distress states develop under such conditions.

Thus, the obtained data allow us to consider the method of integral evaluation of level of mental tension as a rather reliable tool in studying functional states of operators during control of dynamic objects, and to recommend this method in the practice of studies in engineering psychology.

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# A METHOD OF ASSESSING CARDIAC FUNCTION WITH BICYCLE ERGOMETRY IN EXPERT MEDICAL CERTIFICATION OF PILOTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 19 Jul 82) pp 84-86

[Article by E. G. Mukhamedov]

[Text] The use of load tests has made it possible to arrive at quantitative evaluation of cardiovascular function [1, 2]. In the practice of expert medical certification of flight personnel, bicycle ergometry is considered to be the most informative in demonstrating the reserve capacities of coronary circulation [3, 4]. The "double product" is proposed as a parameter reflecting myocardial oxygen uptake, and it is the product of multiplying systolic pressure by heart rate per min, divided by 100 [5-7].

Several authors have shown that there is extension of electrical systole and elevation of systolic index, both at rest and with exercise, when there is a decline in function of the myocardium [8-9]. Extension of the electromechanical systole during bicycle ergometry by more than 15% increases sensitivity of the test, its specificity and diagnostic value in patients with coronary insufficiency [10].

Our objective here was to try to determine the functional state of the myocardium using bicycle ergometry, taking into consideration maximum blood pressure and duration of electrical systole as the most efficient period of the cardiac cycle. In our calculations, we used a parameter, which we arbitrarily called the "systolic product." This is the quotient from dividing by 100 the product of systolic arterial pressure multiplied by the systolic index, or more simply:

$$\text{Systolic product} = \frac{\text{BP} \cdot \text{Q-T}}{\text{RR}} \text{ (in arbitrary units)}$$

where BP is maximum arterial pressure (mm Hg), Q-T is duration of electric systole (in s) and RR is duration of the cardiac cycle (s).

## Methods

We tested 36 flight personnel members with early signs of atherosclerosis (first group) and 60 healthy pilots (second group) 25 to 48 years of age.

The average age of the first group of subjects was  $46.1 \pm 0.78$  years and the second,  $35.0 \pm 0.83$  years. None of the subjects complained about their health, and there were no signs of circulatory insufficiency.

Dynamics of "double product" and "systolic product" during exercise,  $M \pm m$

Step of load	Work performed, kg-m/min		Double product, arbitrary units		Systolic product, arbitrary units	
	1st gr.	2d group	1st gr.	2d gr.	1st gr.	2d gr.
At rest	— (n=36)	— (n=60)	$96,1 \pm 2,07$ (t=2,57)	$89,4 \pm 1,59$	$57,0 \pm 0,95$ (t=5,18)	$50,6 \pm 0,79$
First	$245 \pm 13,1$ (n=36)	$346 \pm 6,2$ (n=60)	$148,1 \pm 4,83$ (t=3,45)	$129,7 \pm 2,26$	$82,9 \pm 2,05$ (t=4,22)	$73,0 \pm 1,14$
Second:						
1st min	$770 \pm 26,7$ (n=36)	$988 \pm 13,3$ (n=60)	$183,5 \pm 7,03$ (t=3,69)	$156,2 \pm 2,33$	$96,9 \pm 2,37$ (t=4,22)	$83,3 \pm 11,5$
2d "	$1306 \pm 39,8$ (n=36)	$1630 \pm 20,9$ (n=60)	$208,6 \pm 8,08$ (t=4,20)	$172,4 \pm 3,02$	$106,9 \pm 2,62$ (t=6,22)	$89,0 \pm 1,19$
3d "	$1835 \pm 52,7$ (n=35)	$2281 \pm 22,8$ (n=60)	$216,7 \pm 8,08$ (t=3,63)	$185,2 \pm 3,16$	$108,5 \pm 2,36$ (t=6,16)	$92,0 \pm 1,27$
Third:						
1st "	$2488 \pm 66,9$ (n=33)	$3083 \pm 31,0$ (n=60)	$232,8 \pm 7,09$ (t=3,50)	$205,8 \pm 3,04$	$114,1 \pm 2,32$ (t=6,07)	$98,6 \pm 1,07$
2d "	$3142 \pm 85,7$ (n=31)	$3881 \pm 36,9$ (n=60)	$251,2 \pm 7,99$ (t=3,69)	$219,6 \pm 3,05$	$120,6 \pm 2,30$ (t=6,90)	$102,9 \pm 1,14$
3d "	$3775 \pm 119,1$ (n=24)	$4681 \pm 43,0$ (n=60)	$249,9 \pm 7,18$ (t=2,50)	$229,8 \pm 3,64$	$119,9 \pm 2,18$ (t=5,48)	$105,9 \pm 1,33$
Fourth:						
1st "	$4583 \pm 161,0$ (n=20)	$5633 \pm 49,1$ (n=60)	$268,2 \pm 8,19$ (t=2,12)	$249,1 \pm 3,79$	$126,8 \pm 2,28$ (t=6,22)	$110,5 \pm 1,29$
2d "	$5409 \pm 240,4$ (n=14)	$6594 \pm 56,6$ (n=56)	$272,9 \pm 10,01$ (t=0,90)	$263,1 \pm 4,29$	$128,1 \pm 2,58$ (t=4,63)	$114,5 \pm 1,40$
3d "	$6135 \pm 327,2$ (n=11)	$7465 \pm 72,5$ (n=47)	$287,1 \pm 8,69$ (t=1,96)	$268,2 \pm 4,24$	$133,0 \pm 2,64$ (t=5,98)	$115,2 \pm 1,37$

Key: t) criterion of reliability of differences between mean group values.

The load test was performed using a KE-11 Medikor bicycle ergometer in seated position, at least 2 h after food intake. Pedaling speed was 60 r/min. The EKG was monitored continuously on a cardiograph and recorded after Neb in three leads on an Electrocardiograph-300T (Yugoslavia) at rest, every minute during exercise and for 10 min in the recovery period. We required continuous pedaling with increase in steps of load, each step lasting 3 min, until the submaximum heart rate for the subjects' age was reached or the criteria to stop the test according to WHO recommendations appeared. BP was measured according to Korotkov each minute of the entire period of investigation. At the same intervals, we determined how much work was performed, calculated the "double product" and "systolic product." Threshold force was calculated from the last step of the exercise load.

## Results and Discussion

Graded exercise had a direct effect on the "systolic product" (see Table).

As can be seen in this table, the systolic product was reliably lower in the second group than the first ( $t = 5.18$ ), even before exercise. With increase in load, this parameter gradually rose in all subjects, but it was higher in those with signs of atherosclerosis than in the healthy subjects ( $P < 0.001$ ), with considerably less volume of performed work.

Overall volume of exercise performed constituted  $4501 \pm 260.9$  kg-m/min in the first group and  $7362 \pm 104.9$  kg-m/min in the second; threshold force constituted  $755 \pm 15.9$  and  $958 \pm 7.0$  kg-m/min, respectively, "systolic product" was  $131.8 \pm 1.93$  and  $116.8 \pm 1.19$  ( $t = 6.62$ ), respectively.

A comparison of "systolic product" and "double product" in healthy subjects revealed a close correlation. Thus, during bicycle ergometry, the coefficient of correlation constituted  $r = +0.89 \pm 0.06$  ( $t = 14.6$ ) at the first step,  $r = +0.81 \pm 0.08$  ( $t = 10.6$ ) at the second,  $r = +0.81 \pm 0.08$  ( $t = 10.6$ ) at the third and  $r = +0.83 \pm 0.08$  ( $t = 10.7$ ) at the fourth.

These data indicate that the change in value of the "systolic product" during bicycle ergometry is very similar in direction to the "double product" parameter. This warrants the assumption that it is quite informative in assessing the functional reserve of coronary circulation.

Also noteworthy is the fact that, at all stages of the study, with comparable load levels, the reliability of differences between mean values for the "systolic product" was considerably higher than for the "double product." Both at rest and during exercise, the "double product" was higher in subjects with early signs of atherosclerosis than in healthy ones ( $P < 0.001$ ). It should be noted that although such a pattern was noted at the height of the load (fourth step), the differences between group parameters were unreliable. At the same time, the differences in "systolic product" between the different groups remained highly reliable throughout the exercise test due to longer duration of electric systole in subjects with atherosclerosis.

The foregoing indicates that, in the presence of early signs of atherosclerosis with adequate myocardial coronary reserve, the proposed parameter could be used as an additional criterion for assessing the functional state of the cardiovascular system in the practice of expert medical certification of flight personnel.

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## EVALUATION OF SKELETAL MUSCLE TONE BY RECORDING LATERAL RIGIDITY

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 29 Sep 82) pp 86-89

[Article by G. I. Gevlich, L. S. Grigor'yeva, M. I. Boyko and I. B. Kozlovskaya]

[Text] Decrease of muscle tone is one of the consistent effects of weightlessness, which has been seen both during real flights and model conditions [1-7]. Apparently, these disturbances, which are related to a change in activity of afferent systems, in particular the musculoarticular and vestibular receptors, could in turn be the source of a number of deviations in function of the motor system, such as reduction of force and rate of muscular contractions, impairment of precise regulation, etc. In space physiology, as in clinical practice, where tonic changes make up a considerable part of all observed disturbances, primarily two methods are used, which are the simplest and, for this reason, the most feasible--determination of lateral rigidity of muscles and EMG amplitude [8] in variants that demonstrate tonic changes when they are relatively gross, for example, following special surgical intervention, in the presence of spastic disorders, parkinsonism, etc. At the same time, there is also a need for more sensitive methods that would permit detection and quantitative description of relatively minor changes in tonus. Our objective in this study was to develop such a method.

## Methods

We refined the method of assessing muscle tone according to parameters of lateral rigidity [9-11] in the direction of selecting an adequate force of application of a gage to measure lateral rigidity, conditions for standardization of position, level of relaxation and degree of contraction of muscles when measuring their rigidity at rest and in an active state.

In our study, we used the electromyotonometer (Figure 1) developed at the Leningrad Polytechnical Institute, which enables us to record the force of application of the gage and tissular reaction over a wide range of strain energy. The instrument consists of a housing (1), case (2), contact screw (3), "pelot" [?] (4), two cushion plates with strain gages (5 and 6) connected into the corresponding bridge circuits of amplifiers. When not operating, the housing, case and "pelot" are movable in relation to one another because of the free movement of stop screws (7 and 8) within the

clearance limits (9 and 10). When the pressure of the tonometer is applied to tissue, the system stiffens due to restricted mobility of the "pelot" when it rests on plate 5 and of the case when contact screw 3 rests on plate 6. In this position, the bottom surface of the "pelot" protrudes in relation to the top surface of the case over a set distance ( $n$ ).

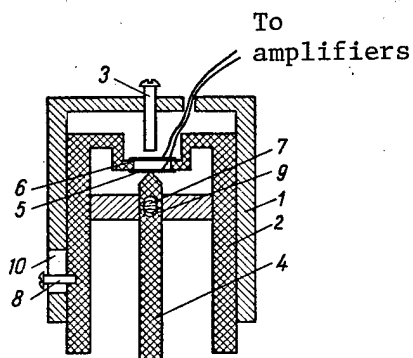


Figure 1.

Diagram of electromyotonometer.  
Explanation is given in the text.

There are grounds to assume that, in the presence of strain [deformation], an intact muscle behaves like an elastic medium [12-14]. On this basis, to calculate the lateral rigidity we applied Hooke's law, which postulates for elastic materials that stress ( $\sigma$ ) and strain ( $x$ ) are proportional:  $\sigma = K \cdot x$ , where  $K$  is a constant.

Upon strain of the muscle by the tonometer applied perpendicularly to its surface, the stress arising under the "pelot" is greater than under the case due to the greater strain (by  $n$  mm). If we know the area of the "pelot" ( $S_{\Pi} = 50 \text{ mm}^2$ ) and case

( $S_c = 650 \text{ mm}^2$ ), as well as overall force applied to the tonometer ( $F$ , recorded by strain gage 6) and force of counteraction of tissue deformed by the "pelot" ( $F_{\Pi}$ , recorded by strain gage 5), we can quantitatively calculate the stress under the "pelot" and case for different forces of application of the gage and then constant  $K$ , which characterizes lateral rigidity or hardness of the muscle:

$$\sigma_{\Pi} = \frac{F_{\Pi}}{S_{\Pi}}; \sigma_c = \frac{F_c}{S_c} = \frac{F - F_{\Pi}}{S_c}.$$

On the basis of Hooke's law:

$$\sigma_c = K \cdot x, \sigma_{\Pi} = K(x + n),$$

hence

$$\sigma_{\Pi} - \sigma_c = K(x + n) - K \cdot x = K \cdot n, \text{ whence}$$

$$K = \frac{\sigma_{\Pi} - \sigma_c}{n}$$

or

$$K = \frac{1}{n} \left( \frac{F_{\Pi}}{S_{\Pi}} - \frac{F - F_{\Pi}}{S_c} \right).$$

Thus, use of this electromyotonometer enabled us to determine lateral rigidity of a muscle with different forces of application of the gage. This makes it possible to define the optimum range of force applied, in which essentially the properties of the muscle itself are tested, rather than superficial layers (skin and subcutaneous fatty tissue).

We tested lateral rigidity of crural muscles of 36 subjects in supine position on a cot, with the foot attached to the pedals of a Cybex dynamometer

so that the angles at the hip, knee and ankle would be 130, 120 and 90°, in accordance with their equitonometric position [15, 16].

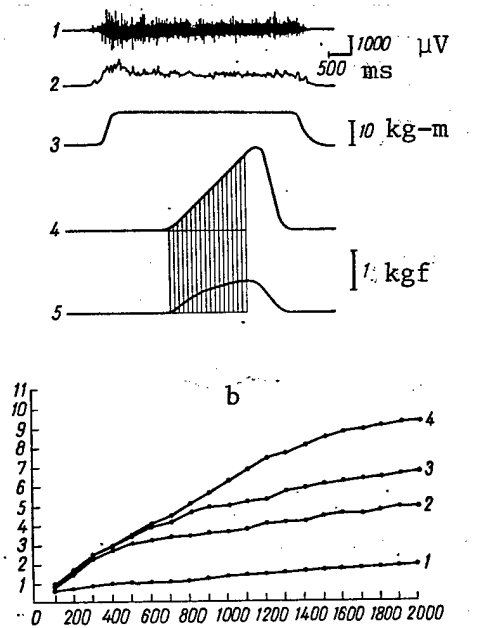


Figure 2.

Sample of unadulterated tracing in testing muscle tone (a) and lateral rigidity of gastrocnemius as a function of external force, at different levels of activity (b)

- a: 1) unadulterated EMG  
2) integrated EMG  
3) dynamogram  
4) force of gage application (F)  
5) resilient force of counteraction upon strain of muscle by "pelot" ( $F_{II}$ )

Vertical lines show increment in force of pressing down gage at 100-g intervals

- b: x-axis, external force (g),  
y-axis, lateral rigidity of tissue ( $g/mm^2$ ) at rest (1),  
with graded (40%--2 and 60%--3)  
and maximum (4) isometric tension

ing a constant level. The range of external forces, in which lateral rigidity of the muscle was relatively stable and, at the same time, differed distinctly with different degrees of contraction, constituting 1000 to 2000 g for this particular instance. The stabilization upon reaching a certain critical level of external force indicates that, in this range of pressure, the deformed

To eliminate the flaws of the method--variability of level of relaxation and activity of muscles--measurements were taken at a standard level of activity, for which purpose we used the training procedure with biological feedback, using the EMG of the tested muscles as feedback signal. Superficial EMG was recorded on an Autogen PT-1 instrument, which permits isolation of an electromyographic signal starting at 0.6  $\mu V$ , as well as its integration and conversion into audio and visual signals.

In measuring lateral rigidity of muscles in an active state, the stress level was standardized according to value of moment of forces recorded with the Cybex dynamometer.

Figure 2a illustrates an example of tracing of lateral rigidity while maintaining maximum exertion: unadulterated and integrated EMG's are recorded, as well as magnitude of developed moments of force, force of application of gage and reaction of muscle. We see that lateral rigidity can be calculated using the above formula for the entire range of force applied to the gage.

#### Results and Discussion

As can be seen in Figure 2b, in the used range of force of application of the gage, the curves of changes in lateral rigidity at different levels of muscular tension were consistent and had two phases. In the first phase, in the range of relatively minimal force of application, lateral rigidity of the muscle increased then, with the change to relatively higher values, it did not change appreciably, approximat-

tissue behaves like an elastic material. In subsequent studies, we tested lateral rigidity of muscles in this range.

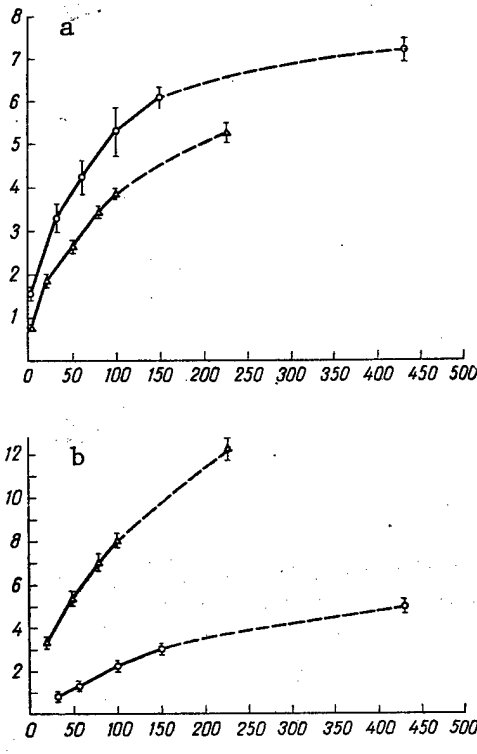


Figure 3.

Lateral rigidity (a) and developed force moments (b) as a function of given level of bioelectrical activity of muscles in isometric contraction

a: x-axis, here and in b, amplitude of integrated EMG (in  $\mu V$ ); y-axis, lateral rigidity of muscles ( $g/mm^2$ )

b: y-axis, force moments (in kg-m). Here and Figure 4:

circles--data for anterior tibial muscle

triangles--data for gastrocnemius

dots on curve--arithmetic means

vertical lines--mean error

tonously at low applied force, and it ceases to change only in the range of medium and high forces [14]. In our studies, the rise of the curve of changes in rigidity in the first phase was apparently due, to some extent, to the influence of the superficial layers (skin and subcutaneous fatty tissue). Apparently, when the gage is applied at low force, the tissular strain is already sufficient for it to submerge into the superficial layers (which also have plastic properties), whereas the strain on the underlying

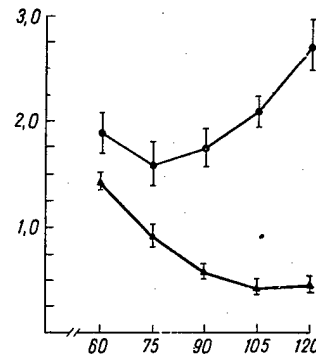


Figure 4.

Lateral rigidity of crural muscles at rest as a function of angle in ankle joint.

X-axis, size of angle (in angular degrees); y-axis, lateral rigidity (in  $g/mm^2$ )

The question of extent to which one can extrapolate to muscle tissue the characteristics of elastic materials is of special theoretical interest and practical importance. Being an anisotropic medium and deafferented, muscular tissue behaves under strain like a nonlinear spring; however, an intact muscle reacts to stretching like a flexible linear spring [12, 13]. Researchers related this to the function of a stretch reflex, in the belief that its function for a given state of a muscle is to maintain a constant level of overall rigidity of the muscle, including a nonlinear, mechanical, elastic component proper and an actively regulated reflex element. Interestingly, as in our studies of lateral rigidity, longitudinal rigidity increases mono-



muscle is still too small for manifestation of its elastic properties. Thus, our results provide a basis for selection of the range of optimum testing of lateral rigidity of muscles--magnitude of force with which the gage is applied, at which there is leveling of the influence of superficial layers of deformed tissue, and it is essentially the elastic properties of the muscle itself that are assessed.

Control of muscle relaxation when recording lateral rigidity at rest increased significantly individual stability and reproducibility of results when readings were repeated. While the coefficient of variation of parameters, when measured repeatedly, ranged from 4 to 46% in different individuals for the anterior tibial muscle (ATM) and from 6 to 20% for the gastrocnemius (GM), constituting a mean of 15 and 12%, respectively, in the case of an uncontrolled level of relaxation, the fluctuations in repeated readings constituted only 2-5% for ATM and 2-7% for GM, averaging 4% for both muscles, with control of relaxation. In other words, the accuracy of individual measurements of lateral rigidity at rest increased by 3 times. We also noted an 11% decline of absolute rigidity for the ATM and 16% for the GM at rest, the individual decline ranging from 2 to 18% and 9 to 35%, respectively.

An analogous increase in stability of parameters with use of control of level of maximum developed muscle tension and measurement of lateral rigidity when the dynamogram reaches a plateau (see Figure 2a). While the coefficient of variation ranged from 3 to 26% for the ATM and 4 to 19% for the GM averaging 13 and 12%, respectively, for the group without controlling the level of isometric contraction, in the case of controlled contraction the fluctuations ranged from 1 to 8% for ATM and 3 to 7% for GM, averaging 4 and 5%, respectively. Thus, stability of individual lateral rigidity of muscles increased by 2-3 times in an active state, with control of contraction. We then observed a tendency toward increase in rigidity parameters, by an average of 16% for ATM and 12% for GM.

Stabilization of individual parameters with controlled level of activity was also reflected in a decline of group variability of data: the coefficient of variation in the group constituted 10% for both muscles in this case (versus 16 and 14% without control) at rest, 8 and 10% for the ATM and GM, respectively (versus 16 and 20% without control), in an active state.

When lateral rigidity of muscles was measured in an active state, with calibration of activity according to the level on the integrated EMG, the rigidity parameters were also characterized by adequate stability, demonstrating consistent increase with increase in EMG amplitude, which was relatively greater for the ATM than the posterior muscle group of the lower leg (Figure 3a). Mean amplitude of the integrated EMG was rather rigidly linked to the magnitude of moment of force developed by the muscle (Figure 3b), which enables us to use it as an argument in studies of lateral rigidity as a function of muscular tension.

Special studies were conducted to examine lateral rigidity of resting muscles as a function of the articulation angle. The results revealed that lateral rigidity of crural muscles changed appreciably with passive change

in ankle angle from 60 to 120° (Figure 4). Within the tested range, rigidity of the GM was at a maximum with an angle of 60°, it diminished uniformly with increase in angle to 90° and changed insignificantly with further increase. Lateral rigidity of the ATM changed in the opposite direction, increasing appreciably in positions exceeding an angle of 100° (105 and 120°). These findings, which confirm data in the literature [17], indicate that it is necessary to standardize the position of a limb to assess muscle tone. They are indicative of the desirability of using an angle in the ankle joint of about 90° in testing crural muscle tone at rest, when rigidity of antagonists is at a minimum, as well as of a standardized flexed position in the knee.

The findings as a whole indicate that, when recording the force of application of the gage and tissue reactions with standardization of position and level of muscular activity, the described method makes it possible to assess with adequate precision and reproducibility the lateral rigidity of muscles, and it can be used in experiments and clinical practice as a means of quantitative evaluation of muscle tone. This conclusion was confirmed in subsequent studies, which involved analysis of the effects of removal of support load, which causes a consistent change in muscle tone [18].

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METHOD FOR IDENTIFYING TRACE CONTAMINANTS IN CHAMBER ATMOSPHERE AT HIGH PRESSURE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 19 Jul 82) pp 90-91

[Article by B. L. Avetisyan, O. A. Sukhorukov, O. N. Skalatskiy and L. B. Zhukova]

[Text] Questions pertaining to formation of the artificial atmosphere in the habitat hold a large place in the problem of life support and maintaining high work capacity in crews of hyperbaric compartments, which could be used, for example, when penetrates deep into the ocean [1]. It becomes necessary to monitor the composition of atmospheric components, the amount of which is permissible only on the level of trace contaminants. The sources of these contaminants are the construction materials and equipment of the complex, the crew and products of their vital functions.

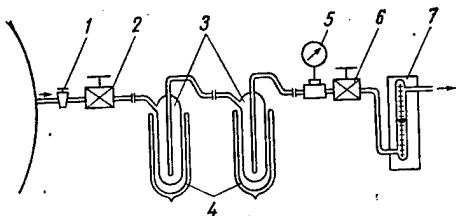
As a rule, the toxicity of some contaminant of the atmosphere is determined by its level and time of exposure at a given partial pressure. For this reason, methods of collection and concentration, which involve bringing the samples to atmospheric pressure, are not suitable because of dilution of samples by the number of times that is a multiple of working pressure in the chamber. It is expedient to concentrate trace contaminants at the working pressure in the hyperbaric chamber.

We describe here methods for collection, concentration and chromatographic analysis of trace contaminants in an artificial atmosphere at elevated pressure.

#### Methods

Three different methods were used to collect and concentrate trace contaminants from the atmosphere at the working pressure in the chamber: system of cryogenic traps cooled by liquid air; passing samples through adsorption traps; use of adsorption traps without pumping (with diffusion delivery of substances to be analyzed).

The Figure illustrates the system for collecting samples from the chamber. The design of the metal cryogenic traps was described previously [2]. The first trap was filled with porous fluoroplastic, the second with silochrome



Drawing of device for collection and concentration of trace contaminants from atmosphere of hyperbaric complex

- 1) stop cock on object
- 2,6) Gofer valves for fine adjustment
- 3) cryogenic traps
- 4) Dewar flasks
- 5) calibrating pressure gage
- 7) rotameter

S-80 in a 10-cm layer. The traps were cooled with liquid air in Dewar flasks. To collect samples from the chamber's atmosphere, we opened valves 1 and 2, and equalized pressure in the traps and chamber, which as monitored with a pressure gage. We slowly opened fine-adjustment valve 6 until the flow of helium and oxygen mixture constituted 0.5-0.8 ml/min. With such flow, pressure in the traps equaled pressure in the chamber. We passed 2 l of the helium-oxygen mixture through the traps in 2-2.5 h at a pressure of 35 atm(gage), which corresponded to 70 l according to readings on the rotameter, which was at atmospheric pressure. Upon termination of collection of samples, the traps were disconnected from the object by means of valves 1 and 2, the pressure in them was slowly lowered to atmospheric level, they were sealed and stored until chromatographic analysis was made.

We used stainless steel tubes, 10 cm in length and with 4 mm inside diameter, which were filled with polymer adsorbent Tenax GC (60-80 mesh), as adsorption traps, with and without pumping samples through them. The specific area of Tenax was 18.6 m<sup>2</sup>/g and average mesh diameter was 114 nm [3]. At the present time, this adsorbent is used extensively for trapping trace amounts of carbons C<sub>4</sub> and higher, alcohols above C<sub>4</sub>, aromatic compounds, esters, ketones and aldehydes [4, 5]. The tubes with adsorbent were connected instead of metal traps 3 on the device illustrated in the Figure, and 2 l helium-oxygen mixture was passed through at a pressure equaling working pressure in the chamber.

The "passive" tubes with adsorbent Tenax GC were assembled into a set of 6 sample collectors and placed in the chamber at the collection site. One hour after reaching the specified pressure, two collectors were opened on one side. They were closed after 5 days and the next 2 were opened, also for 5 days. Calculation of concentrations of trace contaminants at the input of the "passive" collectors C<sub>oi</sub> was made using the following formula:

$$C_{oi} = \frac{Q_i(t)}{lSH_i} \left\{ 1 - \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \times \right. \\ \left. \times \exp \left[ - \frac{(2n+1)^2 \pi^2 D_i t}{4H_i l^2} \right] \right\}^{-1}, \quad (1)$$

where Q<sub>i</sub>(t) is the amount of substance diffused into the tube in time t (determined experimentally from chromatographic analysis); D<sub>i</sub> is the coefficient of diffusion of the contaminant in the gas phase at given temperature and pressure; H<sub>i</sub> is Henry's coefficient of the contaminant in the adsorbent layer, l and S are length and section of the layer of adsorbent.

Solution (1) was obtained making certain assumptions and imposing some restrictions: the concentration at the open end of the tube is constant during the period of collecting a sample; the ratio of length of adsorption tube to collecting time provides for a constant rate of build-up of concentration of contaminant at the close end of the tube; there is no mutual influence of analyzed components with adsorption enrichment.

Analysis of samples from the traps was made on a gas chromatograph with flame-ionization detector in glass columns with inside diameter of 2 mm and length of 180 cm (column A) and 300 cm (column B) with the following phases: column A--Carbopak C (80-100 mesh) with 0.2% Carbowax 1555; column B--10% Carbowax 4000 on WAW chromosorb (60-80 mesh) treated with 4% potassium hydroxide solution.

Conditions of chromatographic analysis were: column temperature 80°C; velocity of gas carrier (argon) 26 ml/min; velocity of hydrogen and air 30 and 400 ml/min, respectively; sample size 250  $\mu$ l. Before analysis, the trace contaminants were desorbed from Tenax and silochrome at 26°C and from porous fluoroplast at 120°C. The chromatograph was calibrated by the diffusion method for benzene ( $C = 0.03$  mg/l). Sensitivity of area reading constituted  $(1.4-1.8) \cdot 10^{-8}$  mg/ $\mu$ V·s for column A and  $(1.0-1.2) \cdot 10^{-8}$  mg/ $\mu$ V·s for column B. The concentration of unidentified substances was determined according to area of peak, without making a correction for sensitivity of the flame-ionization detector.

The cryogenic traps were best for light hydrocarbons (saturated and unsaturated), ketons and alcohols  $C_1-C_4$ , so that the concentrations of these substances, as measured by this method, were substantially higher than when the samples were collected in adsorption traps with pumping, since the retained volumes of the above-mentioned substances constitute less than 2 l for Tenax at room temperature.

Thus, for quantitative analysis of as wide a spectrum of contaminants as possible, when collecting samples with pumping, it is expedient to use a combination of methods or to enlarge the set of adsorbents for adsorption traps. In the case of passive collection, only identified components with known (demonstrable) Henry coefficients are assayed quantitatively. The advantage of the passive collection method is not only that operator work is simple, but that there is widening of the spectrum of quantitatively assayed components with use of one absorber, since mistakes related to escape of poorly sorbed substances are ruled out. Measurement limitations are related only to the range of detection in chromatographic analysis.

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## DEVICE FOR GRADED EXERCISING OF RATS IN PRESSURE CHAMBER

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (manuscript received 28 Dec 82) pp 91-94

[Article by K. S. Yurova and V. M. Potabenko]

[Text] Under laboratory conditions, both closed and open tanks or cylinders of different sizes filled with water are used extensively at normal barometric pressure to make rats and mice swim. The most original devices in their technical execution, which permit investigation of metabolic processes, enzyme activity and the role of the adrenosympathetic system in swimming animals, have been described in the literature [1-6]. In particular, Ardle [4] proposes a closed respiratory chamber, in which the animals are placed above the water surface on a special platform before swimming; this platform slides along the lateral walls of the tank (up-down) by means of an electromagnet. For the animals to swim, the platform is slowly (in 5 min) dropped into water and, as the animals become tired, the platform returns to its initial position.

Use of the above-mentioned devices is difficult in a pressure chamber, because the animals are isolated from the experimenter and are submitted to excess or low pressure. Moreover, under such conditions it is extremely difficult to grade the muscle load for swimming animals, and it is not always possible for them to survive.

Our objective was to develop a device that would permit rapid immersion of animals into water in order to exercise (swim) at different stages of using high pressure and to remove them from water just as rapidly without lowering pressure in the chamber, i.e., to effect both processes (immersion in water and lifting animals out of water) by remote control using a console outside the chamber.

#### Methods

The device consists of a metal tank with a capacity of 85 l. A metal panel (Figure 1A), which is intended to secure the plexiglas cage with removable bottom, with the animals, is attached with bolts to the lateral walls (on the outside). The walls of the cage have many fine holes to allow for air circulation in the cage. The cage can be readily moved along the panel (up-down) and so placed over the water surface that, at the moment the animals are



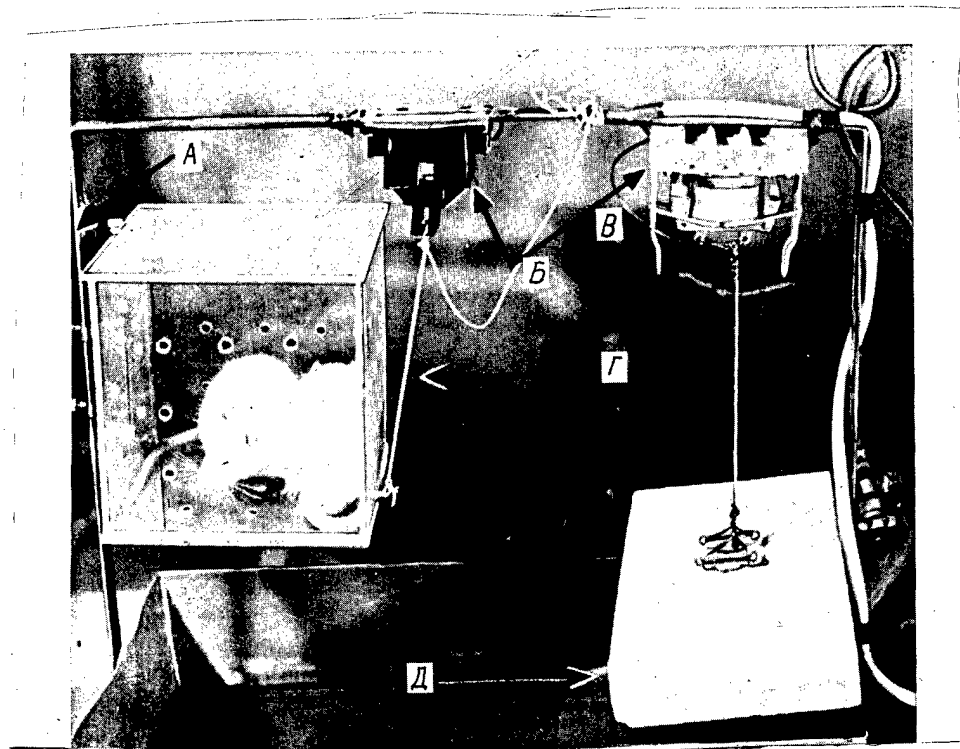


Figure 1. General view of device for exercising animals in a pressure chamber

- |                                |                |
|--------------------------------|----------------|
| A) metal panel                 | Г) cables      |
| Б,Б) electromagnets with cores | Д) "life raft" |

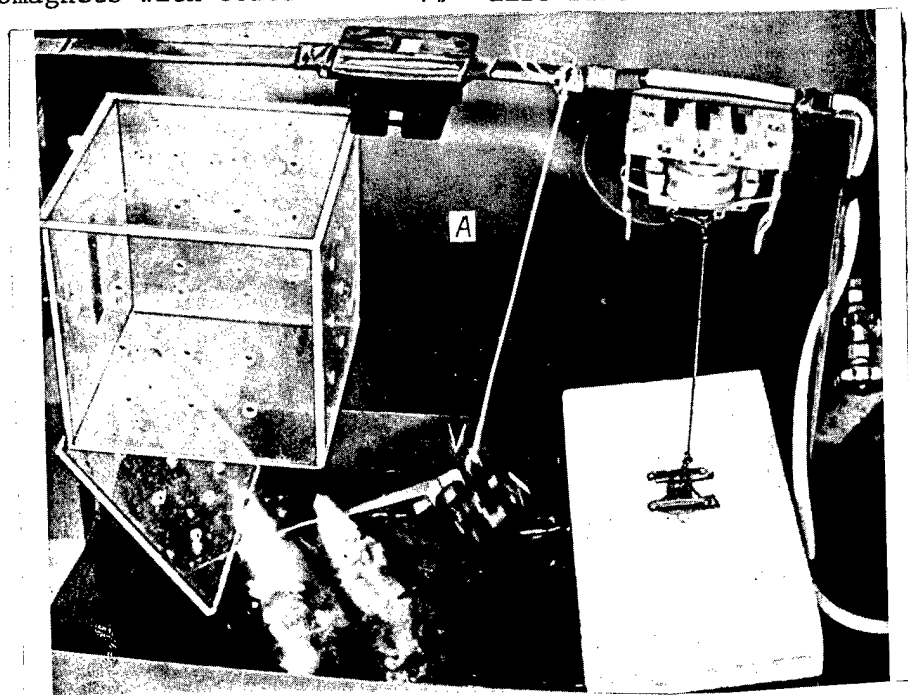


Figure 2. General view of device after dumping animals into tank of water. A--electromagnet core position when power is turned off

dropped into the water, they could grasp the drop-bottom of the cage. Two electromagnets are attached to the top of the panel; they are connected by cables to the hinges of the drop-bottom (Figure 1E) and "life raft" (Figure 1B). On the top, there is shielded electric wiring going to the electromagnets on one side of the metal tank over the panel, with output to the operator's console, which is outside the RKM-2 pressure chamber. The process of dumping animals into the tank of water and subsequent removal is executed from the operator's console by turning off the power to the electromagnets. The metal tank is filled with warm water heated to a temperature of 33-36°C with an ultrathermostat installed outside the chamber. Water temperature in the tank is monitored with an electric thermometer.

The device is considered ready for operation only after the power and cores of the electromagnets, which pull the cables from the bottom of the cage and "life raft" are turned on. The latter is lifted above water to a height that would not enable the animals to jump prematurely out of water and climb on the raft (Figure 1D).

Two or three rats are placed in the suspended cage. It has a lid on the top that is closed with two screws. Then the hatch in the pressure chamber is shut and excess pressure is created in it. After exposure of animals to this pressure, the experimental conditions stipulate that, upon the command to "Immerse" the appropriate tumbler is actuated on the operator's console, which shuts off power. At this moment, the core of the electromagnet drops (Figure 2A). Under the weight of the core, the bottom of the cage drops and the animals are dumped into the water. On the outside of the chamber, the behavior of swimming animals is observed through a port, and upon appearance of the first signs of fatigue, when the animals cannot hold themselves up in water, the operator actuates the "Raft" tumbler, power is turned off, the electromagnetic core separates and the "raft," which is made of a lightweight material (foam plastic) falls into the water (Figure 3).

## Results and Discussion

The device that we assembled turned out to operate reliably. It was tested in 25 tests, which were undertaken to determine animal resistance to decompression disorders when forced to exercise (swim) at the saturation-desaturation stage with immediate or one-step decompression from 4, 5, 6, 7 to 1 kg/cm<sup>2</sup>.

When operating the device, we paid attention primarily to the animals' behavior. During 2-h exposure to excess pressure, they sat calmly in the suspended cage. During the stepped decompression, at the first stop they were instantly dropped into the water by depressing the "Immerse" tumbler. According to the experimental program, the animals had to exercise for no more than 10-14 min, since we soon effected the next step of decompression.

In all of the experiments, the animals usually began to tire by the 7th-10th min; they tried to get close to the wall of the tank and to hold on somehow on the water surface, assuming a vertical position at times. Some animals stopped swimming before the scheduled time, growing tired rapidly, and probably also because they could already have developed symptoms of decompression disorders at the first decompression stop. By this time, at the "Raft" command,

the operator dropped the life raft. The rats climbed on it, shook the water off and dried themselves. After a certain time, pressure was lowered in the chamber to ground level, the chamber was opened and animals removed from it, they were rubbed dry, then put in a warm room where we continued to observe them.

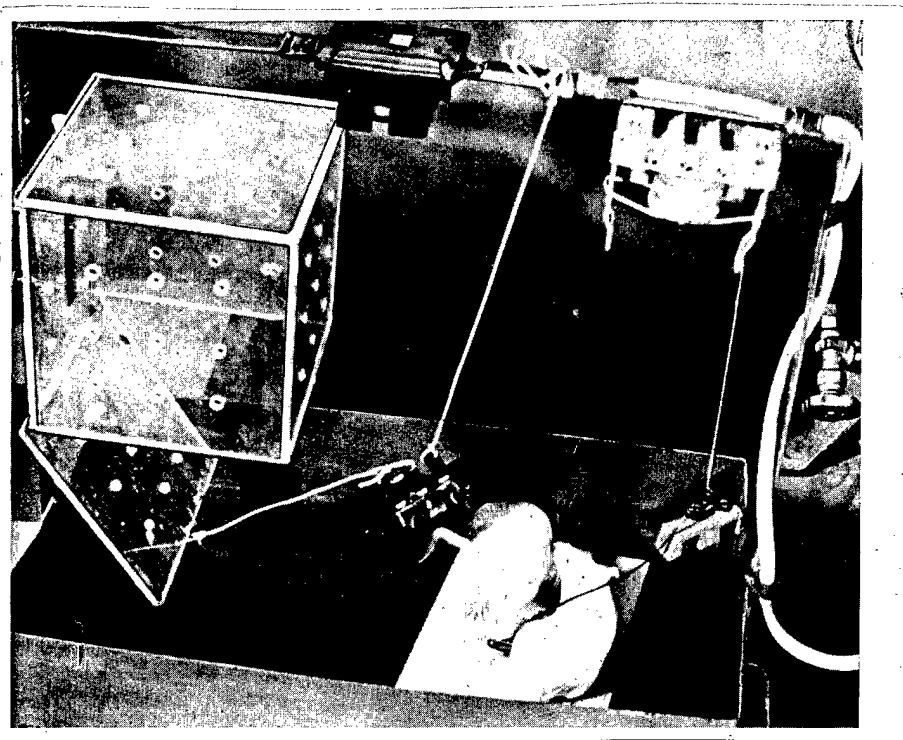


Figure 3. Location of "life raft" after it is dropped into tank to rescue animals

The results of these studies revealed that when animals are forced to exercise in the form of swimming there is appreciable decrease in their resistance to decompression disorders with rise in mortality due to air embolism. We described previously the data on these studies [7].

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## BOOK REVIEWS

UDC: 612.821.1(035)(049.32)

### NEW MANUAL OF ENGINEERING PSYCHOLOGY REVIEWED

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 17, No 5, Sep-Oct 83 (signed to press 9 Aug 83) pp 94-96

[Review by V. I. Myasnikov and A. P. Nechayev of book "Manual of Engineering Psychology", edited by B. F. Lomov, corresponding member of the USSR Academy of Sciences, Moscow, Izdatel'stvo Mashinostroyeniye, 1982]

[Text] This book is the first Soviet methodological handbook for a wide circle of practical workers in planning and design offices and industrial enterprises. The team of authors (B. F. Lomov, B. A. Dushkov, Yu. M. Zabrodin, A. P. Chernyshev and others) performed the large job of systematizing information accumulated in psychophysiology, psychophysics and anthropometry, in the area of design and evaluation of complex systems, organization of labor and the industrial environment. All of this information is united by the authors' interest in matters of interaction between man and machine. The manual was compiled on the basis of generalization of data from 228 original sources, 25 GOST's and 12 State standards for labor safety practices.

The reference material is systematized and presented in the form of seven interrelated chapters reflecting the basic concepts of engineering psychology (first chapter), psychological and psychophysiological characteristics of man (second chapter), engineering psychological requirements of equipment (third chapter), industrial environment (fourth chapter), engineering psychological bases for designing man-machine systems (MMS) (fifth chapter). The sixth and seventh chapters submit data on engineering psychological evaluation of MMS and engineering-psychological bases of organization of labor.

It should be stressed that the concepts of engineering psychology submitted in the first chapter are of special interest to individuals without special education in psychology. The advantage of this section is that there is a classification of methods of engineering psychology and psychophysiology used to assess MMS operation, as well as recommendations for use of methods of recording psychophysiological parameters; there are also indications on equipment (instruments) used with these methods.

In describing the psychophysiological characteristics of analyzer systems, perception and processing of information, the authors devoted special attention (in the second chapter) to properties of memory and operational thinking, logical-psychological structure of the decision-making process. They have

submitted extensive facts for estimation of reliability and time characteristics of operator performance when working with different elements of information display systems (IDS) and controls (C) in the course of retrieval of information and execution of controlling actions.

It is well-known that, in most modern MMS, the operator interacts through mediation with the object of control, using an information model for this purpose. For this reason, the authors have devoted much attention to formulation of specifications for IDS.

The third chapter gives a classification of information display equipment and means of coding, as well as recommendations on choice of indicator features. An important place is reserved in this book to the principles of IDS construction, analysis of advantages and flaws in different types of such systems. In the same chapter, the authors spelled out specifications for controls, serviceability and repairability of MMS, operating documents and organization of the operator's work place. There is a special place for esthetic aspects of design, recommendations on use of colors in rooms, illumination of work places, etc.

The basic characteristics of physical, chemical, biological, sociopsychological and esthetic factors of the work environment are given in the fourth chapter. There is rather thorough consideration of physical and chemical factors, with information furnished about the equipment for studying environmental factors, permissible levels and standards with regard to exposure of man to them, maximum permissible concentrations of trace contaminants, etc.

The fifth chapter is concerned with the main stages of MMS design and tasks referable to consideration of engineering psychological specifications and factors at each stage. The authors give a concrete list of problems that must be solved systematically in the course of furnishing engineering psychological data for the different stages of system development. In essence, the second and third sections of this chapter describe the bases for the engineering psychological aspect of MMS design.

Viewing the MMS as a system with stochastic parameters, the authors familiarize readers with the fundamentals of theory of random processes and describe methods for analysis of this class of systems, listing their advantages and disadvantages. This permits purposeful selection of the required method in designing MMS with due consideration of the possibility of using it, allowances and restrictions.

In the same chapter, analysis is made of methods of constructing mathematical models of operator performance and system as a whole. There is discussion of models of the linear, nonlinear, nonstationary and other types, use of which at the early stages of MMS design saves time and money.

The sections dealing with analysis of maximum operator capabilities and disruption of his performance, as well as psychological support of operators, which is viewed as an element of engineering psychological design, are of definite interest. The authors stress the inseparable relationship between psychological support and increased efficiency of MMS, particularly when it operates in stress situations or under extreme conditions.

The sixth chapter deals with the substance and content of engineering psychological assessment (EPA) which, according to existing GOST's, is a mandatory element of design, development and operation of MMS. The authors list the questions subject to EPA at different stages of MMS development and operation. There is a special place for such system parameters as its reliability and speed of operation. In the second dealing with evaluation of reliability features, there is a list of the principal causes of MMS failure, analysis of mistakes that occur in the course of system operation through the fault of the operator and equipment, with discussion of their effect on system reliability. A mathematical model is described, use of which permits quantitative evaluation of MMS reliability by determining the probability of malfunctions. The manual describes methods for estimating the time spent by an operator to solve a given problem (informational, systematic-structural, network, etc.), with listing of their advantages and flaws. In the same chapter are listed engineering psychology parameters, according to which the MMS is assessed, with discussion of principles and methods of formation of special and complex parameters. Considering the difficulty of obtaining EPA by analytical methods, the authors devote a special place to the method of expert evaluations and its execution on computers. They also describe the procedure for algorithmic analysis of operator performance and demonstrate its capabilities with respect to solving problems of distributing functions in an MMS, and they offer recommendations on use of analytical methods and the method of statistical modeling on a computer to check and prevent conditions that cause an information overload for the operator.

The aggregate of methods used for EPA of MMS makes it possible to provide an economic assessment of the system, including such parameters as annual economic effect, coefficient of economic effectiveness, time in which the expenses for engineering psychological measures are repaid, etc. The manual gives formulas and describes the procedure for calculating the above parameters, so that designers of automated systems can objectively evaluate the efficacy of engineering psychological design, not only from the standpoint of quality, but quantity.

The seventh chapter deals with engineering psychological bases of organization of labor. The authors describe the principles for organizing working conditions, as well as rest for operators that provide for high efficiency and its retention on the required level. They describe methods of reducing the negative effect on work capacity of factors such as monotony and intensity of work. A special place is given to questions of professional training of operators and providing for group interaction when working in small groups.

There is a special section dealing with methods of monitoring an operator's state and performance. It also furnishes qualitative characteristics of different psychophysiological parameters at different levels of tension and the corresponding quantitative equivalents. Brief information is given on methods of regulating the operator's state (autotraining, physical conditioning, electro-acupuncture, etc.) to enhance efficiency of the MMS as a whole.

There were some difficulties involved in the authors' desire to furnish extensive factual material in a manual of limited size, and this could not

help but affect the quality of the book. It has some flaws. First of all, we refer to the absence, in most cases, of references to bibliographic sources in the descriptions of mathematical methods used to design and assess the MMS, constructing models of it, questions of psychological support, structure of small groups, etc. Such references would have enabled the reader to orient himself better in the special literature. Incidentally, as we see from the contents of the manual, the authors had planned to provide a list of recommended reading with each chapter, but unfortunately such an index is absent from the manual. In our opinion, there should have been a more detailed description of the general structural method and method of statistical standard, which would have expanded the reader's knowledge about modern approaches to MMS design.

It would have been desirable to give more details about the recommendations on use of man's peripheral field of vision and, in IDS, use of combined, paravisual and other types of instruments in the section dealing with the design of information display systems.

There are statistical and editorial flaws in this manual. For example, in the seventh section of Chapter 5, which deals with the effect of characteristics of the controlled object on quality of operator performance, it would have been more correct, in our opinion, to speak of deliberate choice of system features, rather than those of the controlled object, since in a number of cases the parameters of the latter are set on the basis of structural considerations and it is impossible to change them. There is no explanation in the text of the block diagram for compensatory tracking (Figure 102 on p 267), the alphabetical designations in formula (14) on page 104 are not fully identified, not all of the curves on the graph illustrated in Figure 51 (p 105) have digital designations, and moreover two of the curves are designated with the same numbers, which makes it difficult to comprehend the submitted material.

However, these flaws do not minimize the great merit of the team of authors, who did much to generalize and systematize extensive material in the design, from the standpoint of engineering psychology, and evaluation of ergatic systems.

Undoubtedly, this manual deserves high praise, and it is a valuable reference and methodological aid for scientists and specialists concerned with the study, development and operation of MMS.



DOCTORAL DISSERTATIONS IN THE FIELD OF SPACE AND AVIATION MEDICINE  
APPROVED BY THE USSR HIGH DEGREE COMMISSION

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No 5, Sep-Oct 83 (signed to press 9 Aug 83) p 96

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[Text] Bayev, V. I., "Metabolism in Animal Tissues During Adaptation to Acute Hypoxia in an Altered Gas Atmosphere and With Cooling" (Institute of Biomedical Problems, USSR Ministry of Health, 12 Mar 82).

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